IMPROVED METHODS AND EQUIPMENT TO CONDUCT PAVEMENT DISTRESS SURVEYS

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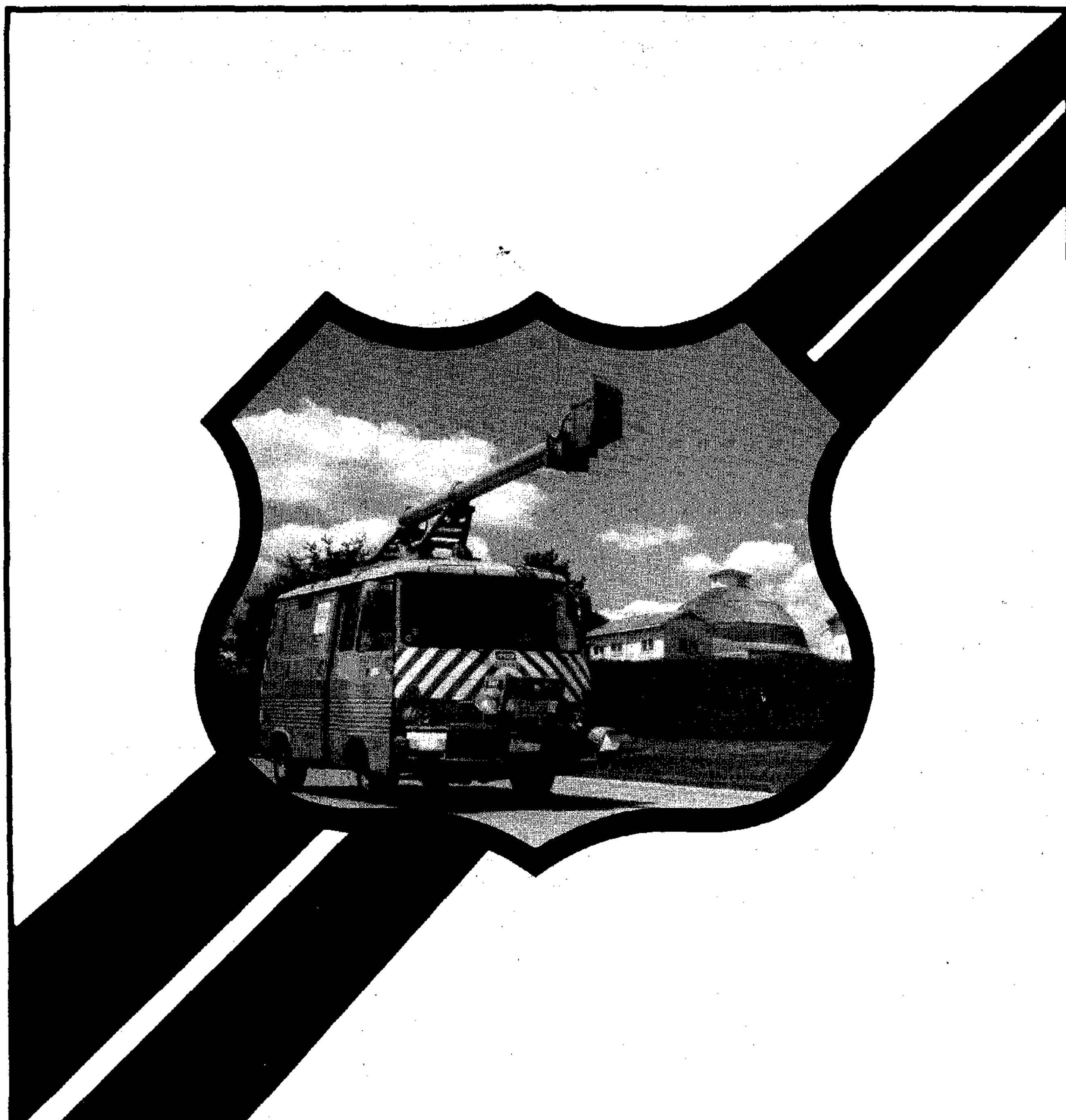

FOREWORD

This report documents the results of an evaluation of selected pavement distress survey methods and devices. Included in the evaluation were a manual mapping method, detailed visual surveys using manual recording and automatic data logging, the PASCO Roadrecon survey vehicle, the GERPHO device, the ARAN survey vehicle, and the Laser RST device. Each method and device was field tested on several flexible, rigid, and composite pavement sections exhibiting a wide range of distress. Evaluations were based on observations during the field testing and analysis of the collected data.

This report should be of interest to those individuals involved with pavement evaluation procedures and equipment. Additional copies may be obtained from this office or the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161.

R. J. Betsold, Director
Office of Implementation

NOTICE

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16. Abstract

This report documents the second phase of an FHWA study, entitled "Pavement Condition Monitoring Methods and Equipment". In this phase selected distress survey methods and devices, representing a range in automation, were tested from July to September 1986. The following methods and devices were included in the testing: manual mapping, detailed visual surveys using manual recording and automatic data logging, PASCO ROADRECON survey vehicle, the GERPHO survey vehicle, the ARAN survey vehicle, and the Laser RST survey vehicle. The field tests were conducted on flexible, rigid, and composite pavements exhibiting a range of pavement distresses.

The survey devices were evaluated using performance, capability, efficiency, and cost-effectiveness criteria. The study concluded that, at present, the GERPHO and PASCO ROADRECON are best suited for pavement performance research studies due to factors such as the permanent film record, cost-effectiveness, and data quality. The GERPHO and PASCO ROADRECON are also judged to be suitable for network and project level surveys. The ARAN and Laser RST were recommended for consideration for use in network level surveys for pavement management. It is also recommended that data loggers be used to record field data for traditional manual survey techniques.

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*These tables provide evaluation results for various distress survey devices and methods. The tables contain a great deal of information, and much narrative discussion is needed to fully explain the results. To keep the text as brief as possible, only Tables 15, 21, and 24 appear in the body of the report. These tables provide the reader with a sample of the available information. If additional details are desired, the reader can refer to Appendix C where all the tables are included along with complete discussions.

By organizing the report as described above, Tables 15, 21, and 24 each appear at two separate locations. In addition, the other tables with asterisks are listed on pages which at first may seem to be out of sequence.

CHAPTER 1. INTRODUCTION

The Strategic Highway Research Program (SHRP) will produce results in the areas of pavement design, construction, and rehabilitation. One phase of this program is entitled "Long-Term Pavement Performance (LTPP)" and will involve the collection of uniform evaluation and performance data on numerous pavement sections throughout the United States. A study has been initiated by the Federal Highway Administration (FHWA) to assist in this effort by providing a better understanding of the procedures and devices used to evaluate pavements. This study, "Pavement Condition Monitoring Methods and Equipment," consists of three phases. The first phase involves the evaluation of pavement deflection measuring devices and equipment for detecting voids under rigid pavements. The second phase examines improved methods and equipment for conducting pavement distress surveys, and the third phase will develop a training course for the collection and reporting of uniform pavement evaluation data. This report documents the second phase of the study in which selected distress survey methods and devices were tested and evaluated.

Pavement distress surveys, popularly called condition surveys, are an important part of any pavement performance study or management system. The information collected from distress surveys is used to document the performance of a pavement and can help determine appropriate rehabilitation alternatives. Distress surveys usually begin with a visual survey of the pavement. Distresses and other pertinent information are recorded on specially designed data forms, then transcribed into a central computer for storage, processing, and future use. Techniques to automate both the collection and transfer of data to central computers have been developed. This has ranged from the use of handheld data loggers to instrumented survey vehicles which carry on-board computers. To help establish differences between the automation, capabilities, efficiency, and cost-effectiveness of some of these techniques, this study investigated a select number of techniques ranging from manually drawn maps to instrumented survey vehicles. Comparison of these techniques was performed by conducting surveys over a set of test sections with each method.

OBJECTIVE AND SCOPE

The objective of this research is to establish the performance capabilities and limitations of selected methods and devices used to conduct pavement distress surveys. This report includes:

- Evaluations of distress survey techniques using increased levels of automation.
- Field tests of selected distress survey techniques to document capabilities, performance, efficiencies, and costs.
- Comparisons and ratings of the distress survey techniques investigated.
- Recommendations on cost-effectiveness of distress survey procedures.

OVERVIEW OF THIS REPORT

Seven distress survey techniques, which use increasing levels of automation, were selected for field tests. The selection of the techniques and their descriptions are presented in Chapter 2. In Chapter 3, the plan for evaluating the techniques, the selection of test sections, and the field test plan are presented. Arrangements for equipment availability in Austin, Texas, observations and monitoring of each tested device, and a summary of field testing work are presented in Chapter 4. Chapter 5 presents the field data analysis. Chapter 6 presents an evaluation and comparison of the selected equipment. Conclusions and recommendations are presented in Chapter 7.

Details of many of the topics presented in the text of the report are contained in appendices to this report. Appendix A provides a detailed description and operating procedure of the selected distress survey devices. Details of the field testing and sample field data are presented in Appendix B. Appendix C presents a detailed discussion of the distress data reported on each test section by each method. Appendix D provides a cost analysis of the selected distress survey methods.

The evaluation of distress survey techniques and devices depends on the intended use of these techniques. This investigation and evaluation of the distress survey techniques was primarily approached from the perspective of use in pavement performance research studies. Due to this primary perspective, greater emphasis was placed on the collection of detailed data and information that can serve as a permanent record of a pavement's condition, allowing multiple interpretations by future researchers, than to collection of summary information more suited for pavement management purposes. To make the information presented in this report useful to a broad range of readers, discussions of the basis of our judgments and ratings are presented. Recommendations are included in Chapter 7 on the use of distress survey techniques and equipment for network and project level pavement evaluations for pavement management purposes. Readers interested in efficient distress survey techniques for these types of planning and management purposes should keep our primary perspective in mind and interpret the information contained in this report in light of their intended use and criteria.

CHAPTER 2. DISTRESS SURVEY PROCEDURES AND EQUIPMENT

INTRODUCTION

Pavement distress surveys, often called condition surveys, are used to quantify the condition of a road by classifying the amount and extent of distress present at any given time. These surveys are traditionally performed by raters who travel along the road and classify the distresses based on their visual observations. These observations and their location are recorded on data forms used to transfer the information into files in the office. This type of manual procedure is slow, labor intensive, and subject to transcription errors. Consistency between classification and quantification of the distresses observed by different raters can also be a problem. Once the data has been summarized and corrected for transcription errors, the only recourse for checking apparent anomalies in the data is a return visit to the field.

Methods have been devised by various agencies to standardize distress classifications and to speed up the process by automating the recording, reduction, processing, and storage of the data. Condition survey manuals which define distress classifications using pictures and detailed descriptions have been developed to minimize interpretation errors between raters. Some procedures employ detailed measurements of the distress to minimize quantification errors. Small hand-held computers and data loggers have been used to speed up recording and transfer of data from the field to the office computer. Vehicles which take photographs or other visual images of the pavement to be later interpreted in the office were developed to speed the field data collection time and provide a permanent visual record of the actual pavement condition. Other survey vehicles carry on-board microcomputers for manual entry, recording, and storage of the data directly in the field. A new class of condition survey vehicles are emerging which use objective measures of the pavement surface to classify and quantify different types of distress. The direction of current development in distress survey equipment is the use of video imaging to take a picture of a portion of pavement and, by using pattern recognition technology, classify and quantify pavement distress directly without subjective evaluation of human raters. This last set of survey vehicles is still in the development stage.

The type of condition survey performed depends on its intended use. Condition surveys for network level screening of sections to receive more in-depth study may consist of a windshield survey of the roads where only two or three types of distress are rated. At the other end of the spectrum are detailed condition surveys for research purposes. This type of survey attempts to precisely classify and quantify all distresses and other features of a pavement section which may influence its performance. For research purposes, it is also desirable to have a visual record of the pavement surface that may be examined in a time sequence to observe the development of distresses, interpreted independently by other researchers, or used to detect other features of a pavement which lead to the development of distress but are not included in standard condition surveys. The required level of effort and cost to conduct these different types of condition surveys varies with the intensity of the data collection effort.

SELECTION OF DISTRESS SURVEY PROCEDURES AND EQUIPMENT

To study improved methods to conduct distress surveys, a variety of distress survey procedures employing different levels of automation were selected and used to rate a group of pavement sections exhibiting a wide range of distress. The base level of distress surveys was a labor intensive manual mapping of the distress on the pavement sections. The next level was use of a detailed procedure in which raters walking along the side of the road rated and recorded the distress information on data sheets. A detailed survey was also conducted using an automated field data logger to record the distress ratings. The next level of automation was the use of photographic survey vehicles whose pictures were interpreted in the office. Two other survey vehicles which combined the use of on-board computers to record data and objective measures of the pavement surface to detect and quantify certain types of distress were investigated in this study. The following survey procedures and automated equipment were selected for investigation in this study:

- o Manual mapping, AASHO Method.
- o Detailed visual survey, manual recording, PAVER and COPES methods.
- o Detailed visual survey, automated data logger, ARE Inc data logger.
- o PASCO ROADRECON Survey Vehicle, multi-function survey vehicle featuring photographic equipment and laser height sensors.
- o GERPHO, photographic survey vehicle.
- o ARAN, multi-function survey vehicle featuring video equipment, ultrasonic height sensors, and on-board computer.
- o Laser RST, multi-function survey vehicle featuring laser height sensors and on-board computer.

DESCRIPTION OF SELECTED PROCEDURES AND EQUIPMENT

A detailed description of each method and device investigated in this study is included in Appendix A. Brief descriptions of each procedure and device are presented here.

Manual Mapping

The manual mapping method used in this study consisted of a rater walking the pavement section and manually drawing a map showing the type and exact location of all distresses present on the pavement section. This procedure was similar to the one used at the AASHO road test (Ref 1). The severity level of each distress was identified and recorded on the map. The mapping form shown in Figure 1 was used to record the distresses. To aid in mapping, a 100-foot (30.5 m) tape, marked in 5-foot (1.5 m) intervals was placed along each subsection of the test pavement. The distress mapping form was also marked in 5-foot (1.5 m) intervals. All distresses were identified and measured according to the standards found

DISTRESS MAP

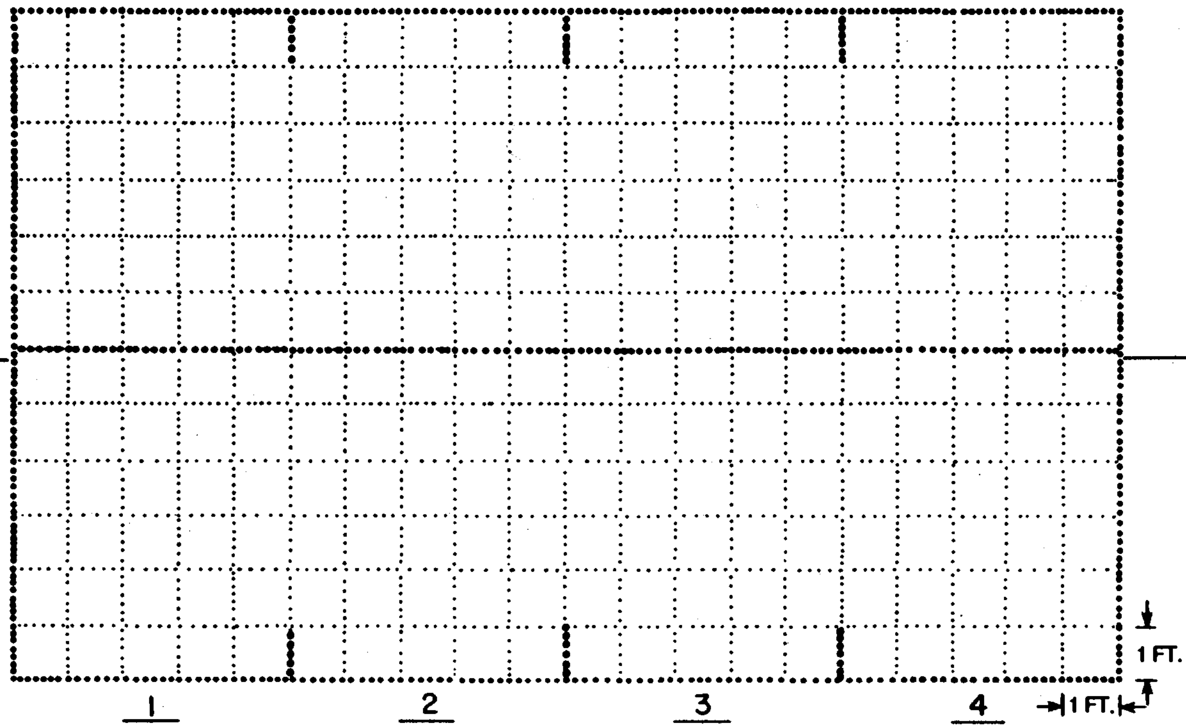
FHWA Project: Pavement Condition Monitoring Methods and Equipment
ARE Project No. FH-67
4 AUG 86

Date of Survey__________
Time Arrived__________
Time Started__________
Time Completed__________

Section No. and Identification__________
Subsection Identification__________

Rater__________
Air Temperature__________
Weather: Dry / Wet
Clear / Cloudy
Direction__________
Lane Width__________

START



FINISH

Comments:__________

L = Low Severity
M = Medium Severity
H = High Severity

Figure 1. Manual mapping form used in the field to record distresses and severity levels.

in the "Highway Pavement Distress Identification Manual" (Ref 2). Other features and distresses that could not be drawn on the mapping form (e.g. pumping, bleeding, etc.) were noted in the comments section of the form.

Detailed Visual Survey

The PAVER and COPES methods of conducting condition surveys were selected as representative detailed visual distress survey methods. PAVER is a pavement evaluation system developed by the U.S. Army Construction Engineering Research Laboratory (Ref 3). The detailed condition survey procedure employed by the PAVER system was used for the flexible, composite, and JRCP pavement sections in this study. According to this procedure, pavements are broken into sample units and a selected number of sample units are surveyed to represent the entire pavement. For the purposes of this study, the entire length of the test section was rated. A two-person field crew is recommended with one person to measure distress density while the other person records. Interaction between the two members in "calling" distresses is a check used on personal bias in the interpretation of each distress. Equipment used to carry out the field inspection includes a hand odometer to measure slab size and distress lengths, a 10-foot (3.1 m) straightedge and scale to measure rut depths, clipboards for a writing surface, a supply of field forms (Figure 2) and the "APWA PAVER Pavement Condition Index Field Manual" (Ref 4). A Pavement Condition Index (PCI) is computed by weighting the observed distresses to determine deduct values which are summed and subtracted from 100. This PCI allows sections with different types and severity of distresses to be compared against each other.

The COPES distress survey method was used to rate continously reinforced concrete pavements since PAVER was not developed for CRCP. COPES (Concrete Pavement Evaluation System) was developed in an NCHRP study (Ref 5) for evaluation of the three types of conventional concrete pavement including: plain jointed, jointed reinforced, and continuously reinforced concrete pavements. The recording method is shown on the data sheets in Figure 3.

ASPHALT OR TAR SURFACED PAVEMENT
CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

BRANCH ______________ SECTION ______________

DATE ______________ SAMPLE UNIT ______________

SURVEYED BY ______________ AREA OF SAMPLE ______________

Distress Types		SKETCH
1. Alligator Cracking	10. Long & Trans Cracking	
2. Bleeding	11. Patching & Util Cut Patching	
3. Block Cracking	12. Polished Aggregate	
4. Bumps and Sags	13. Potholes	
5. Corrugation	14. Railroad Crossings	
6. Depression	15. Rutting	
7. Edge Cracking	16. Shoving	
8. Jt. Reflection (PCC)	17. Slippage Cracking	
9. Lane/Shldr Drop Off	18. Swell	

	EXISTING DISTRESS TYPES					
TOTAL SEVER L						
M						
H						

PCI CALCULATION				
DISTRESS TYPE	DENSITY	SEVERITY	DEDUCT VALUE	COMMENTS
				PCI = 100-CDV = ______
DEDUCT TOTAL				RATING = ______
CORRECTED DEDUCT VALUE (CDV)				

Figure 2. Field data form used for PAVER condition survey.

SHEET 2F

UNIFORM SECTION FIELD DATA

-COPES-

Record No.	6.	1
State Code	__ __.	2-3
Proj. ID	__ __ __ __.	4-7
Unif. Sect.	__ __.	8-9
Time Sequence	__ __.	10-11

UNIFORM SECTION SURVEY

Uniform Section Location:

Start Pt. Mile Mark ______________

End Pt. Mile Mark ______________

Start Pt. Station No. ______________

End Pt. Station No. ______________

*U 1. Date Surveyed (day/month/year):

__ __/__ __/__ __ 12-17

*U 2. Foundation:

Majority at grade 1 18
Majority in cut 2
Majority in fill 3

*U 3. Depth of Typical Cut:

5 ft. or less 1 19
6-15 ft. 2
16-40 ft. 3
Greater than 40 ft. 4

U 4. Typical surface drainage in cut or at grade:

H* less than 2 ft. ..1 34
H between 2-5 ft. ...2
H greater than 5 ft..3
Tied Concrete Curb ..4

Other ______________5

*H=Distance from top of slab to bottom of side ditch or natural ground if no ditch.

U 5. Height of typical fill:

5 ft. or less 1 35
6-15 ft. 2
16-40 ft. 3
Greater than 40 ft. .4

36/BK

Record the number of occurances for each lane at each severity level.

	Distress Type/ Location	Left Lane Severity L	Left Lane Severity M	Left Lane Severity H			Right Lane Severity L	Right Lane Severity M	Right Lane Severity H	
U6L.	Depressions	__ __.	__ __.	__ __.	20-25	U6R.	__ __.	__ __.	__ __.	37-42
U7L.	Swells	__ __.	__ __.	__ __.	26-31	U7R.	__ __.	__ __.	__ __.	43-48

		Left Lane			Right Lane	
*U8L.	Mean Panel PSR	__.__	32-33	U8R.	__.__	49-50

*Variables that were found to be highly important.

Figure 3. Sample field data sheet for COPES condition survey (Ref 5).

Automated Data Logger

The detailed distress survey using a field data logger was performed using a battery operated Epson HX-20 portable computer programmed by ARE Inc to record distress and section information. The interactive program prompts the rater for input of the severity and extent of each previously defined distress category. The information is stored on a computer encoded microcassette. This allows the information to be downloaded in the office using hardwired connections between computers and a communications program. Paper tapes are also produced in the field as the information is recorded to serve as backup. The automatic data logging keyboard is shown in Figure 4.

Flexible pavement sections were rated using a procedure developed for the Rhode Island Department of Transportation by ARE Inc (Ref 6) since the Epson was already programmed for this procedure. The distress categories were similar to those used in the PAVER system. The distress categories and severity levels from the COPES method were used for rigid pavement sections.

PASCO ROADRECON Systems

PASCO Corporation of Japan developed the continuous pavement surface photographing device (ROADRECON-70) in the late 1960s. The first operational survey vehicle was produced in 1970. This was also the year that the first patent in Japan was granted. In 1975, development and production of a photographic rutting measurement survey device (ROADRECON -75) was completed. Development of the automated system of analyzing the rutting measurements using a digitizing table was completed in 1983. The survey vehicle used on this project made measurements with the two types of longitudinal profilers. One longitudinal profiler used a tracking wheel, accelerometer, and differential transformer to measure the surface elevations in the outer wheel path (ROADRECON-77). The other longitudinal profiler measured the distance between the vehicle body and the road surface using three infra-red lasers, one in each wheel path and the other in the center of the vehicle (ROADRECON-85B). This device was also used as

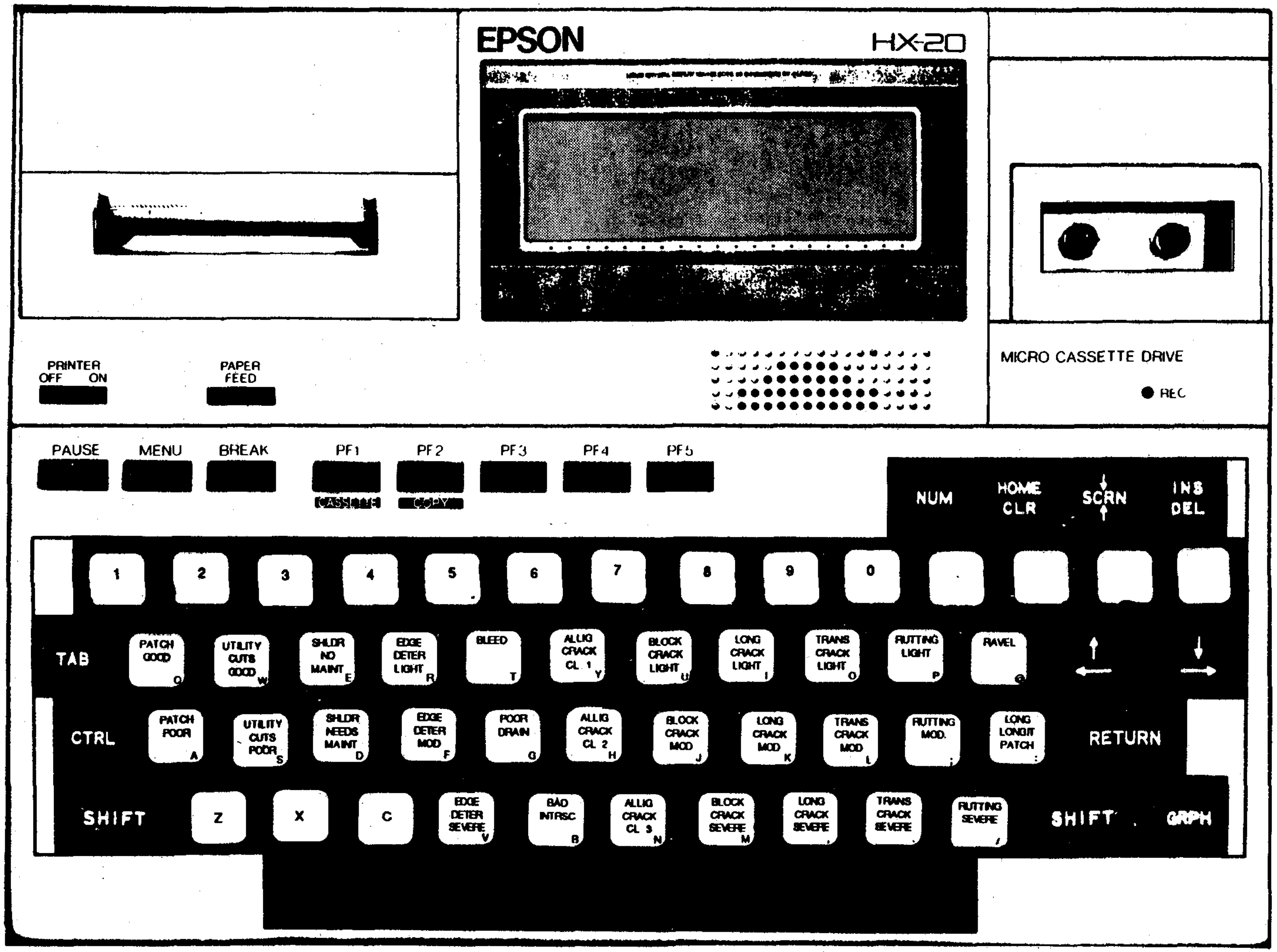


Figure 4. EPSON HX-20 keyboard used for automatic distress data logging.

an approximation of rut depth since each wheel path is measured. The measurements with the ROADRECON-85B is not a true profile since the movement of the vehicle body is not subtracted from the height measurements. The PASCO survey vehicle also has other devices for measuring pavement surface characteristics as described below and in Appendix A. This study concentrated on the continuous photograph made with the ROADRECON-70 and the rut depth measurements performed with the ROADRECON-75 device. The ROADRECON survey vehicle and systems used for this study are illustrated in Figure 5.

Cracking, patching, and other distresses are recorded using a continuous road surface photographic recorder, called the ROADRECON-70 system (Ref 7). The vehicle travels at speeds between 3 and 53 mph (5 and 85 kmph). A continuous photographic record of the pavement surface is made using a 35-mm slit camera. The system synchronizes film feed speed and camera aperture with the speed of the vehicle in order to equalize image density and photographic reduction. A continuous film record of approximately 37 miles (60 km) of road can be created with 1000 feet (305 m) of film. Road width up to 16 feet (5 m) can be filmed. Photographing is performed at night using on-board lights. The lights are set at an angle to the road surface so that shadows are produced at cracks and other defects in the surface, making interpretation easier. Interpretations of the distresses present on the road are made by a technician viewing the developed 35-mm film enlarged ten times on the ROADRECON Film Digitizer. A grid pattern is overlayed on the film to aid in quantification of the distress for input into a computer data base.

Rut depth surveys can be carried out at speeds up to 50 mph (80 kmph) using the ROADRECON-75 system (Ref 8). A pulse camera mounted on the vehicle photographs hairline optical bars projected onto the road. The camera shutter and hairline projector are synchronized according to the distance covered by the projection vehicle, so the system is able to create a photographic record of rutting over a given distance. The film is projected onto a digitizing table and traced with a computer "mouse", enabling the wave patterns to be processed into a transverse profile of

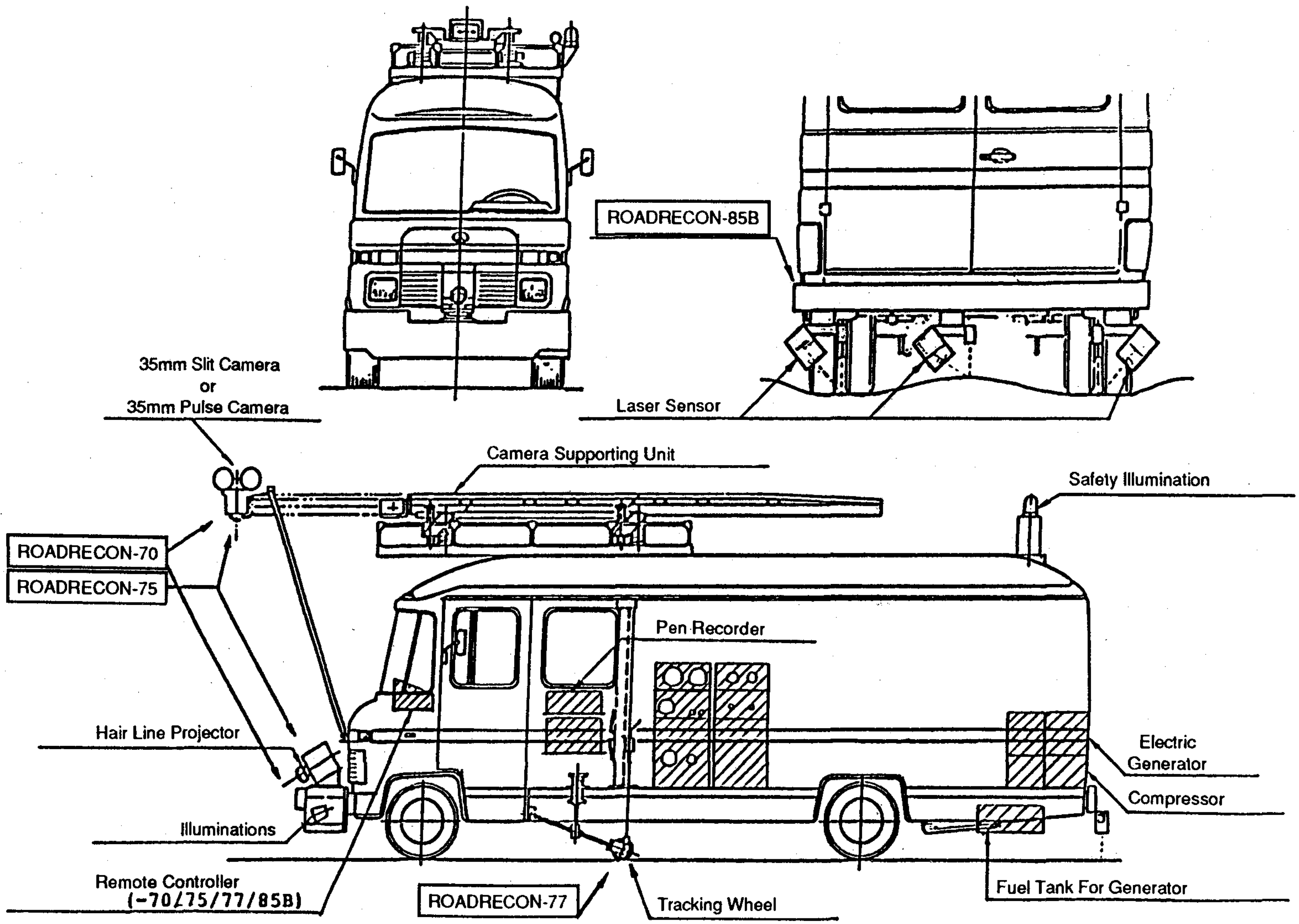


Figure 5. PASCO ROADRECON system featuring automated photographic equipment and laser sensors (Ref 8).

the pavement surface. From this transverse profile, rut depth computations can be made with a computer using any desired definition of rut depth.

Longitudinal roughness can be measured with the ROADRECON-77 by means of a tracking wheel, differential transformer, and an accelerometer. Longitudinal profile measurements can be made with this device at speeds up to 38 mph (60 kmph). The data is stored on magnetic cassette tapes or plotted on a strip chart. Roughness is expressed as the standard deviation of the pavement profile measurements.

A high speed automatic longitudinal and rutting survey device (ROADRECON-85B) was developed to measure longitudinal profile, including joint faulting, joint seal failure, and rutting at speeds up to 50 mph (80 kmph) (Ref 8). Three laser sensors, mounted on the rear bumper, are used to measure the longitudinal profile in the center of the vehicle and in both wheel paths. The data is recorded on magnetic tape and/or a paper chart. The data on the cassette magnetic tape can be read by a computer and processed.

GERPHO System

The GERPHO (Groupe Examen Routier Photographic) System, developed in France by the French Ministere Des Transports, employs a survey vehicle to take continuous 35-mm photographs of the pavement surface (Ref 9). The GERPHO system has been used extensively in France since 1972. It has also been used to a limited extent in several other countries, including Spain, Portugal, and Tunisia (Ref 10). This system is similar to the PASCO ROADRECON-70.

The GERPHO system consists of a 35-mm continuously-running (strip film) camera, mounted on a van with a light source that illuminates the pavement as illustrated in Figure 6. The pavement surveys are conducted at night to allow for uniform lighting conditions. The boom mount allows the height of the camera to be varied for easy loading of the film. The camera is fitted with a 14.5-mm lens with an aperture of F-3.5. Automatic cartridges hold 394 feet (120 meters) of film and can

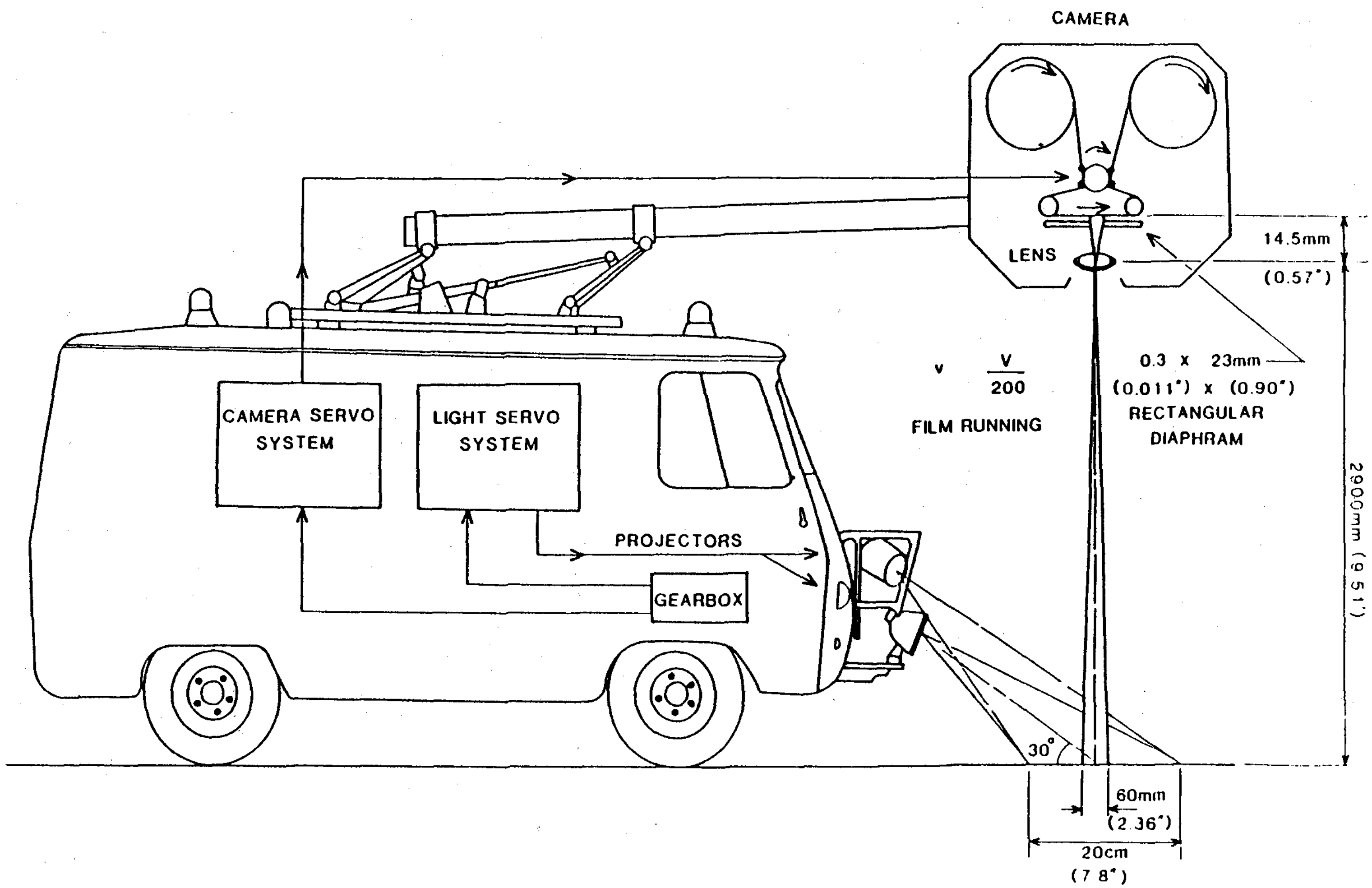


Figure 6. Schematic illustrating principles of GERPHO's automated photographic system (Ref 9).

photograph 15 miles (24 km) of pavement. The scale used is 1/200 (the film useful width divided by width of filmed pavement) which means that the camera lens should be placed at 9.5 feet (2.90 m) above the pavement (focal length/height = 1/200). The picture covers a width of pavement up to 15 feet (4.6 m). Thus, the picture covers the entire traffic lane along which the van moves, together with part of the adjacent lane and/or part of the shoulder (Ref 9). The film and light source are controlled as a function of vehicle speed. The GERPHO system takes a continuous image of the pavement surface at speeds up to 40 mph (60 kmph). Between 63 to 125 lane miles (100 to 200 km) can be photographed per working night. Two operators, who do not have to be highly skilled, are required.

The visual analysis of the negative films for distress data collection is done with a viewing table, and the data storage and reduction with an operating station. The screen of the viewing table can show two rolls of films simultaneously, representing the equivalent of 65 feet (20 m) with a magnification of four. The distress data is directly entered into a microcomputer using a keyboard equipped with a special template of distress codes. The microcomputer, the special keyboard, a CRT, and a printer forms the operating station.

Automatic Road Analyzer (ARAN)

The Automatic Road Analyzer (ARAN) vehicle is produced by Highway Products International, Inc. of Paris, Ontario, Canada. An ARAN Model III unit was used in the field tests of this project (Figure 7). It measures rut depth and transverse profile with ultrasonic sensors, ride/roughness quality with an accelerometer on the rear axle, takes a video picture of the road right-of-way through the windshield, takes a video picture of the pavement surface with a shuttered video camera behind the vehicle, and uses an on-board microprocessor to record distress data (Ref 11). Seven ultrasonic sensors on 12-inch (30.5 mm) centers, mounted in a front-bumper rut bar, are reported by the manufacturer to measure the distance to the pavement surface with 1-mm precision at operating speeds up to 55 mph (90 kmph). Additional sensors and bar extensions can be used to extend the

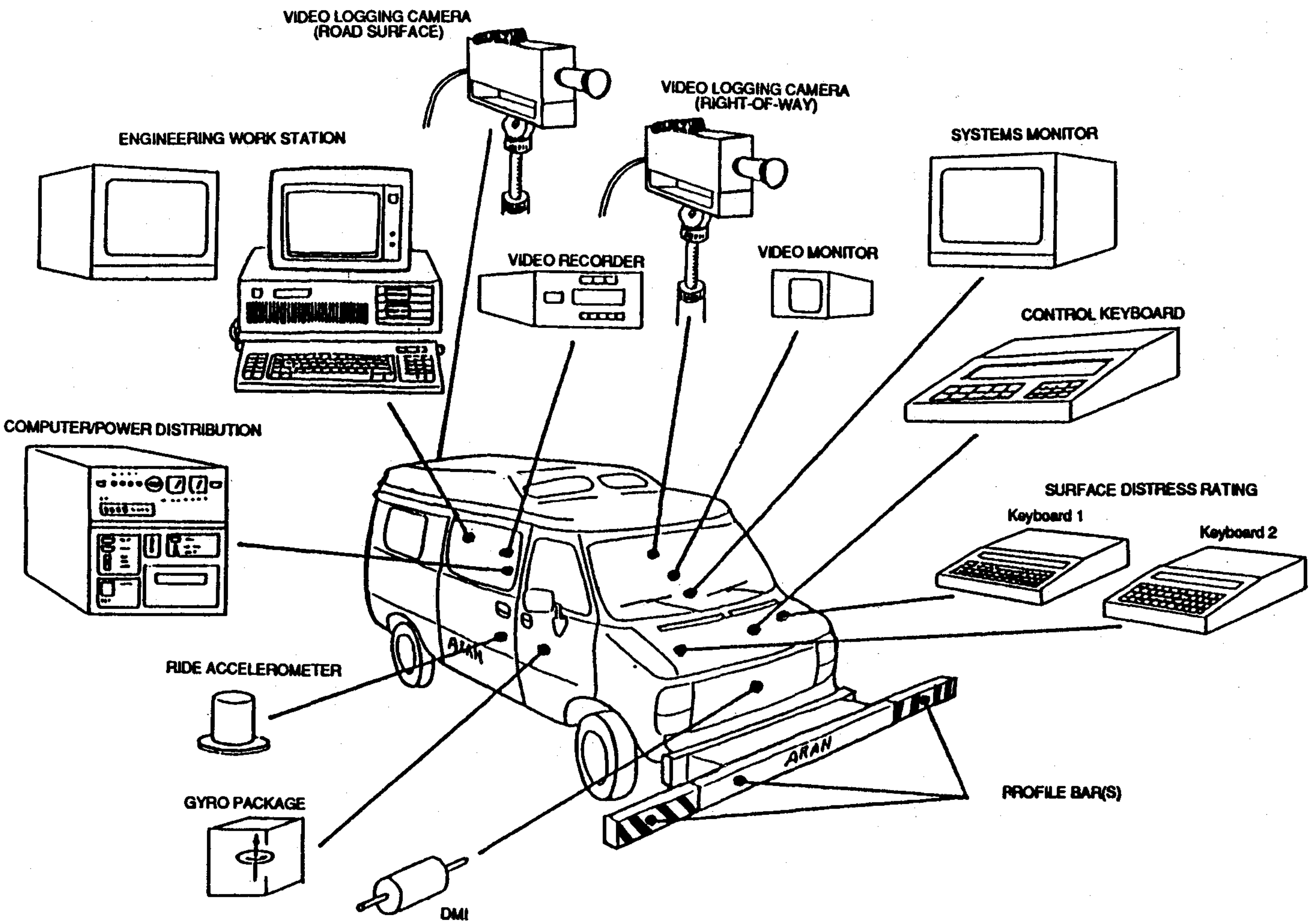


Figure 7. Schematic illustrating various components of HPI's automatic road analyzer (ARAN) (Ref 11).

rut bar to a width of 10, 11, or 12 feet (3.1, 3.4, or 3.7 m). A calibration sensor is used to compensate for changes in air density due to temperature variation. Microprocessor-controlled, plug-in optional keyboards, with built-in liquid crystal displays, automate the collection and recording process. Dual keyboards have the capacity to handle up to 20 distress categories in three severity categories and five degrees of areal extent. Landmarks, such as bridges and railway crossings, can be recorded using eight special-event keys. The video equipment operates from a 12-volt power supply.

<u>Laser Road Surface Tester (RST)</u>

The Laser Road Surface Tester (RST) was developed by the Swedish Road and Traffic Research Institute and has been used in Sweden for about three years (Ref 12). The Laser RST can reportedly measure crack depths and widths, rut depths, longitudinal profile from which roughness is computed, macrotexture, cross profile, and distance. A "windshield" condition survey can also be performed by one of the operators to identify types of cracking and other distresses. The device tested on this project uses eleven bumper-mounted laser range finders and an accelerometer to measure the transverse road profile and detect cracks while traveling at speeds of 18 to 55 mph (30 to 80 kmph) (Ref 13). A pulse transducer, mounted on the wheel hub, measures the distance traveled by the unit. Seven of the lasers pulse at 16 kHz and are used for the rut depth measurements. Four of the lasers pulse at 32 kHz and are used for measurement of rut depth and cracking. Two of these lasers are used for macrotexture and longitudinal profile measurements. These lasers have a reported accuracy of 0.01 inches (0.26 mm). An on-board microcomputer integrates the sensor signals with the accelerometer and distance transducer, averages the data into manageable sections, and provides the processed data in real time. A set of eight three-position toggle switches are used to rate types of cracking and other distresses. An illustration of the Laser RST is shown in Figure 8. The Laser RST is available in the United States only under a lease agreement with Infrastructure Management Services. Three operators are required for normal operations with one operator well-trained in setup and use of the equipment.

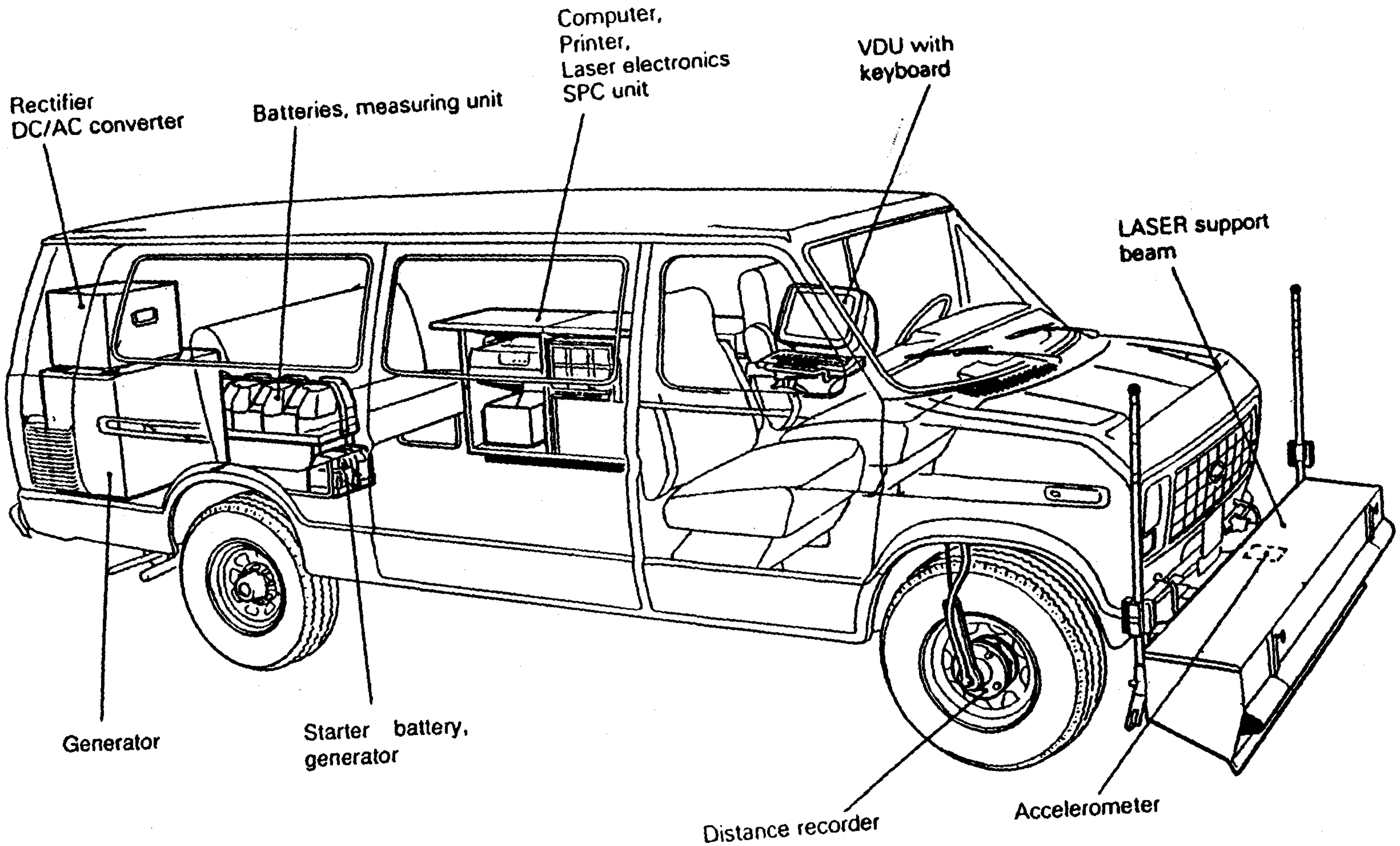


Figure 8. Schematic illustrating various components of IMS' Laser Road Surface Tester (RST) (Ref 13).

EQUIPMENT SOURCES

The equipment sources and raters used to perform the testing on this project are shown in Table 1. The ARE Inc staff performed the manual condition survey, manual mapping, and condition survey using the data logger. The other sources of selected equipment were the only manufacturer or technical representatives for the equipment available in the USA. Telephone numbers and addresses of the distress survey participants are given in Appendix B.

Table 1. Sources of distress survey methods and equipment.

Distress Survey Method/Equipment	Sources
Mapping (Raters)	ARE Inc staff
Detailed Visual Survey, Manual Recording (Raters)	ARE Inc staff
Detail Visual Survey, Automated Data Logger (Epson HX-20, Raters)	ARE Inc staff
GERPHO (GERPHO van, data processing station, operators and other representatives)	MAP Inc, Washington, D.C. MAP-International Division, Mulhouse, France
PASCO-ROADRECON (1-in-3 van, operators and representatives from Japan)	PASCO USA Inc. Lincoln Park, New Jersey, USA
ARAN (ARAN van, data processing station, operators and representatives from Canada)	Highway Products International, Inc. Paris, Ontario, Canada
LASER RST (RST van, operators and representatives)	Infrastructure Management Services Arlington Heights, Illinois, USA

CHAPTER 3. EQUIPMENT EVALUATION AND TESTING PLAN

The evaluation of the selected methods of conducting distress surveys is complicated by differences in distresses measured or rated by each method, methods of collecting the distress information, techniques for transferring the data to computer for processing, methods of interpreting the data, and differences in the type of information and records produced as the end product of each method. The evaluation plan in this chapter presents our approach to the evaluation of the selected distress survey methods. The criteria for comparison of the methods are presented. The primary source of information upon which our evaluations are based is a field test of the selected methods and devices. The field tests were devised to develop first-hand, comparable information on the cost and efficiency of each procedure, operational characteristics, and levels of automation provided by the equipment and procedures tested. The development of the field test plan and the selection and classification of test sections are also presented in this chapter.

COMPARISON CRITERIA

The criteria for comparison and evaluation of the distress survey methods and equipment are listed in Table 2. The criteria are separated into four categories of equipment requirements, operating characteristics, costs, and other considerations. Information in the categories and topics listed in Table 2 were collected in order to compare and contrast each procedure and device. A discussion of these criteria is presented in the following sections.

Equipment Requirements

The type of equipment used for field measurements, field data collection and storage, and transfer of field data to computer data base, form the primary difference between the level of automation offered by the types of condition survey methods investigated. Information on the type of equipment being used, its operating principle, objective features of the pavement surface measured, the interaction and interface between

Table 2. Criteria for comparison and evaluation of distress survey methods and equipment.

1. Equipment Requirements

   (a) Field measurement equipment
   (b) Field data recording equipment
   (c) Data transfer/processing equipment
   (d) Data storage/retrieval equipment
   (e) Level of automation
   (f) Vehicle requirement

2. Operating Characteristics

   (a) Distress categories included in rating
   (b) Field data collection rate (productivity)
   (c) Restrictions on field data collection
   (d) Crew size
   (e) Operator training requirements
   (f) Office data processing time
   (g) Raw data storage and retrieval requirements
   (h) Processed data storage and retrieval requirements
   (i) Quality of raw data
   (j) Reproducibility of measurements
   (k) Operating speed
   (l) Maintenance requirements

3. Costs

   (a) Equipment costs
      (1) Capital cost
      (2) Lease arrangements and warranties
      (3) Routine operating costs
      (4) Maintenance cost

   (b) Labor costs
      (1) Traffic control cost
      (2) Field data collection and processing cost
      (3) Office data processing cost
      (4) Data storage costs
      (5) Data retrieval cost

   (c) Total program costs

4. Other Considerations

   (a) Field validation
   (b) Robustness, durability, and reliability of equipment
   (c) Versatility of equipment
   (d) Current production status

measurement and recording equipment, and vehicle requirements were collected and organized to compare the level of automation of the mechanized techniques against the typical manual techniques.

Operating Characteristics

The operational characteristics of each method were investigated and measured through field tests. Operating characteristics of the field data collection methods include the distress categories rated or measured, method of rating each distress, field data collection rate or productivity of the field data collection, restrictions on collection of field data, survey crew size, and special operator training requirements. For the methods employing measurements with instrumented vehicles, the set-up requirements, calibration procedures and reproducibility of measurements were studied during the field testing. Because each method and device rate, measure, and classify pavement distresses differently, this information is an important part of the comparison.

Other operating characteristics considered for comparison included field data processing requirements, raw data storage and retrieval methods, quality and usefulness of the raw data, and storage and retrieval of the processed data.

Costs

An important aspect of this study is estimation of the cost-effectiveness of various selected methods. The information required to estimate cost-effectiveness includes equipment costs, labor costs, and total program costs for a specified number of production units, like lane miles of an existing road. Lease arrangements, warranties, service facilities, and availability of spare parts were compared. Routine operating costs and maintenance costs were estimated. Labor costs include costs for field data collection and processing, traffic control cost, raw data processing in office, data storage, and data retrieval. Where information on production rates, labor costs, service life of equipment, etc. was lacking, educated assumptions were used based on, to the maximum extent possible, information obtained from users, manufacturers and the field tests.

Other Considerations

Several other considerations included in the comparison plan are discussed below.

Field Validation. Typical manpower-intensive visual distress survey procedures are proven methods in spite of the subjective element of the rater, which is always present in these procedures. Every state has adopted these procedures to fit specific needs. The relatively new methods, especially the methods involving some type of objective measurement of distresses, were compared against the findings of the visual surveys during field tests.

Robustness, Durability, and Reliability of Equipment. The primary issue in this case is how to evaluate a relatively new device in comparison with devices that have been in service for a longer time. The long-term experience of users is generally limited for new devices. However, long-term performance of devices that are in service for several years can be easily evaluated from the results of user surveys. The results of field tests and information obtained from the manufacturers and from literature were used for the evaluation of equipment durability, reliability, and robustness.

Versatility of Equipment. This is the degree of automation the equipment offers to its users, the usefulness and reasonableness of data, and the adaptability to consider specific distress survey requirements. Measuring and reporting of distress survey data is not uniform among these devices and methods. Particularly, the automated equipment of foreign origin process data and generate reports in formats which are significantly different from the requirements of a highway agency or research study in the United States. The adaptability of devices and methods to specific distress survey requirements was, therefore, an important consideration in this evaluation plan.

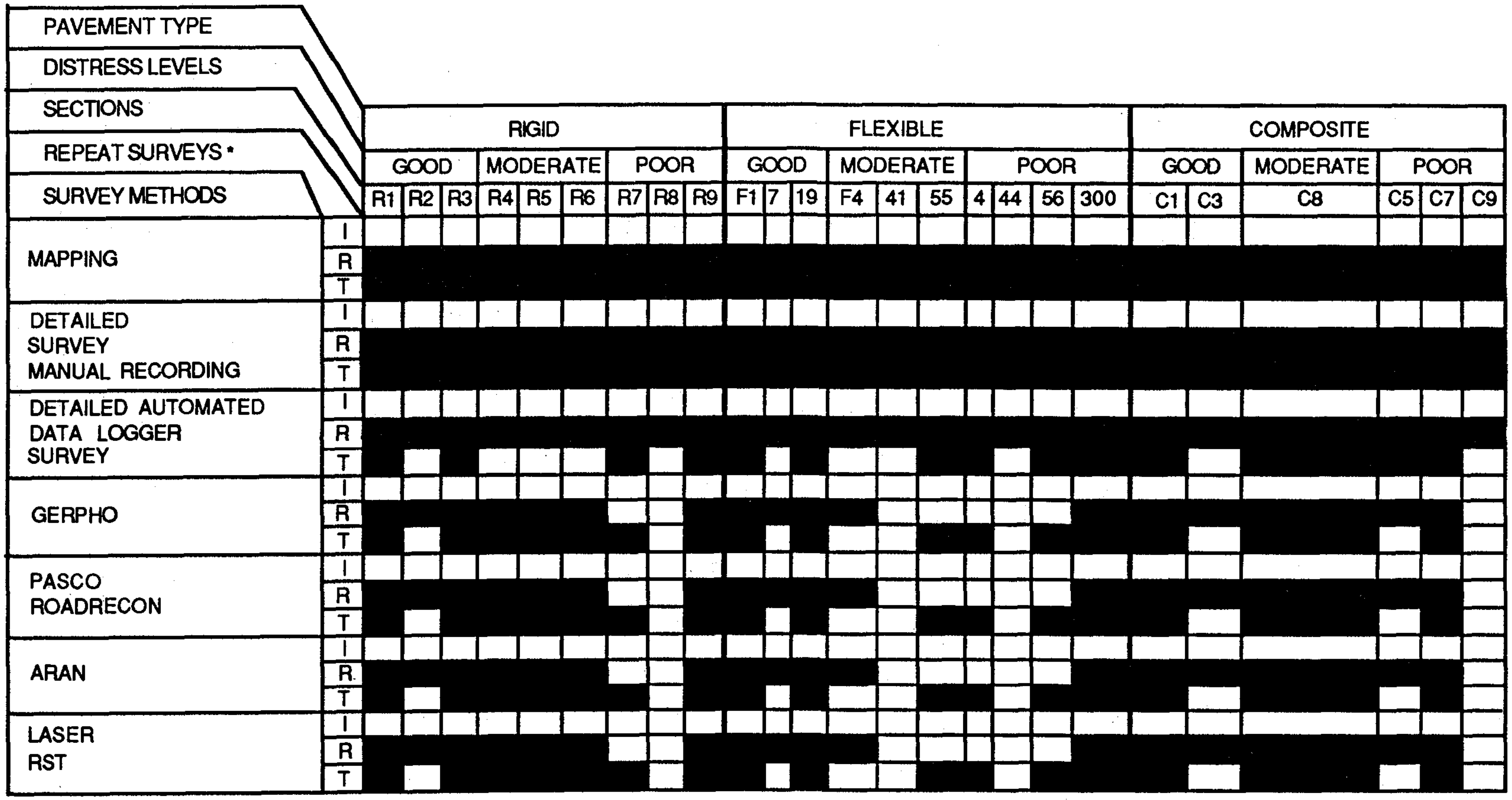
Current Production Status. This information is equally vital for users of this comparison study in order to find the availability of a specific selected device for future use.

TEST SECTION SELECTION

Test sections were selected to represent rigid, flexible, and composite (flexible overlay on a portland cement concrete (PCC) pavement) types of pavement structures exhibiting good, moderate, and poor levels of distress. Potential locations were surveyed by members of the study staff and classified into the three distress level categories based on their subjective opinions. Three sections for each combination of pavement type and condition were sought, however due to practical considerations, this was not possible for all of the composite pavement combinations. Twenty five test sections, located in the central Texas area to minimize travel time, were selected.

A combination factorial, which shows the number of test sections selected for each combination of pavement type and distress level, is shown in Figure 9. This figure also shows each type of distress survey and the time of repeat measurements. The first letter of some of the test section designations indicates the type of pavement structure. F represents a flexible pavement, R a rigid pavement, and C a composite pavement. The sections designated with a number only are flexible sections which are part of a series of roughness calibration sections located in the Austin area. The exception is Section 300 which is located adjacent to the ARE Inc offices. Details of the locations and cross section characteristics of the selected test sections are located in Appendix B.

All of the rigid pavement test sections, except two, were continuously reinforced concrete pavements. The two jointed reinforced concrete pavement test sections, Sections R4 and R7, classified in the moderate and poor distress categories, were selected as representative of jointed PCC pavements. No jointed unreinforced PCC sections were located that could be conveniently included into the study. However, similar



* I = Initial test, R = Repeat test (immediately after initial test), T = Replicate test (on a different day).

Figure 9. Example of factorial combination of factors for field evaluation experiment.

types of distresses are observed on both unreinforced and reinforced jointed pavements.

Each test section was 1000 feet (305 m) long. The test section designations were marked with white reflective paint on the pavement surface at the beginning of each section. The sections were divided and marked at 100-foot (30.5 m) intervals. All of the sections were located on in-service trafficked roads. The test sections on multi-lane highways were located in the outside lane, except sections F1 and R7 which were located on the inside lane.

FIELD TEST PLAN

In order to obtain meaningful results from the surveys conducted on the selected test sections, experienced raters and trained equipment operators were used for each procedure. The manual mapping, detailed condition surveys, and detailed condition surveys using the data logger were performed by ARE Inc personnel who had previous experience in performing the type of survey conducted. The surveys performed with the instrumented survey vehicles used the operating configuration, standard test procedure, and equipment operators which the manufacturer or technical representative consider to be most appropriate. The same operators were used for each method and device for all tests.

Repeat measurements were made with the instrumented survey vehicles and the automated data logger. These measurements with the survey vehicles were performed to see how well the devices repeated themselves. The repeat measurements with the data logger were performed by a different rating team to get a better measure of the benefits of using this level of automation. As shown in Figure 9, three types of tests were performed on a subset of the test sections. Surveys on some of the sections were performed immediately after the initial survey was completed. These were called repeat measurements. Measurements were also conducted three to four days after the initial survey. These were called replicate measurements. The section numbers were changed for the replicate measurements in an effort to reduce bias from the previous measurements made on the sections. These were referred to as blind replicate sections. The section designations for the blind replicate sections along with the type of facility the test sections were located on are listed in Table 3.

The time required for the collection of field data by each method and any problems encountered were monitored by the study staff. The time required to perform the surveys using the manual methods were recorded on the field data sheet by the project staff conducting the survey. An ARE Inc staff engineer rode in the survey vehicles during their field tests and kept a field log.

It was initially planned to conduct side-by-side tests of all the devices. Due to scheduling difficulties and time constraints, the field surveys were instead performed at different times over a three-month time period. The test sections were monitored on a regular basis by the study staff to detect any significant changes in the distresses present on the sections or any maintenance to the section which would change its characteristics.

Table 3. A list of distress survey sections.

Pavement Sections Type	Condition	Section*	Designations for Blind Replicate Sections (T)	Type of Facility
Rigid	Good	R1	---	State Highway (SH)
		R2	101	SH
		R3	---	Interstate Highway (IH)
	Moderate	R4	---	SH
		R5	---	IH
		R6	---	IH
	Poor	R7	---	SH
		R8	105	IH
		R9	---	IH
Flexible	Good	F1	---	SH
		7	7	Primary Highway (US)
		19	---	US
	Moderate	F4	100	SH
		41	200	Farm to Market (FM) Road
		55	---	FM
	Poor	4	---	Country Road
		44	201	Country Road
		56	---	Country Road
		300	---	Country Road
Composite	Good	C1	---	IH
		C3	104	US
	Moderate	C8	---	IH
	Poor	C5	102	IH
		C7	---	SH
		C9	103	US

* Section identification used for initial and repeat tests.

Note: All rigid sections are continuously reinforced concrete pavement except R4 and R7 which are jointed reinforced concrete pavements.

CHAPTER 4. FIELD TESTING OF SELECTED METHODS AND EQUIPMENT

Field testing of selected distress survey methods and equipment was performed during the months of July, August, and September 1986 in the central Texas area. Key steps to arrange field testing work and to collect distress data and reports follow.

- Arrange availability of the selected equipment in Austin.
- Finalize a detailed testing schedule and provide the schedule and related information to the participants.
- Make arrangements for monitoring and coordinating field tests.
- Arrange traffic control and coordinate with the Texas SDHPT.
- Meet with the operators and crew of each participating method or equipment to explain section locations and other project requirements.
- Perform field testing according to the schedule and following the plan of the designed experiment.
- Take slides and photographs of the distress survey methods and equipment and the field test operations.
- Obtain test data reports, equipment literature, and other pertinent information from the participants.

PREPARATION FOR FIELD TESTING WORK

Considerable planning and coordination was required to schedule and conduct the field testing. Key items performed in preparation for the field testing included:

- Location and marking of test sections in the Central Texas area.
- Finalization of detailed test plans and field data collection.
- Preparation of information packages on test sections and list of deliverables for the participants.
- Traffic control arrangements.

Information Package

An information package was given to each participant. This contained detailed information and instructions regarding the field testing data collection and deliverables, including:

- Test locations.
- Test schedule.
- Routing and sequence in which the device would perform initial, repeat and replicate tests.
- Monitoring of set-up and operation.
- List of distresses proposed for use by the Federal Highway Administration (FHWA) as shown in Table 4.

The participants with automated high-speed devices were also asked to supply the following information:

- Raw test data, with identification of section and test type, as soon as possible.
- Other standard output from on-board computer and/or data processing station.
- Processed data, or the results of office data interpretation, later, at the option of the participant.
- Operator's manual or written operating procedure, description of the device, and procedures of data interpretation.
- Additional capabilities and other aspects of the equipment (like the history of its use) at the participants' option.

In addition, the participating automated high-speed equipment teams were told the following items:

- We would like for an ARE Inc staff member to participate in the data interpretation and to perform independent interpretation of some selected test data using your equipment.

Table 4. Preliminary list of distress data requirements for long-term pavement performance study (Ref 16).

Flexible Pavements:

Distress	Units of Measurement
Alligator/Fatigue Cracking	Square Feet
Raveling	Square Feet
Bleeding	Square Feet
Block Cracking	Square Feet
Longitudinal Cracking	Linear Feet
Transverse Cracking	Linear Feet
Potholes/Pothole Patching	Number
Reflection Cracking	Linear Feet
Lane/Shoulder Drop-Off	Mean Severity Level
Lane/Shoulder Separation	Mean Severity Level
Rutting	Square Feet

Jointed Concrete Pavements:

Distress	Units of Measurement
Blowups	Number
Transverse Joint Spalling	No. of Joints
Longitudinal Joint Spalling	No. of Joints
Joint Load Transfer Associated Deterioration	No. of Joints
Pumping and Water Bleeding	Highest Severity Level
Longitudinal "D" Cracking	Linear Feet
Transverse "D" Cracking	Linear Feet
Longitudinal Cracking	Linear Feet
Transverse Cracking	Linear Feet
Lane/Shoulder Dropoff	Mean Severity Found
Lane Shoulder Separation	Mean Severity Found
Corner Breaks	Number
Reactive Aggregate	Percent of Area
Joint Faulting	Mean in Inches

Continuously Reinforced Concrete Pavements:

Distress	Units of Measurement
Transverse Crack Spalling	Linear Feet
Longitudinal Crack Spalling	Linear Feet
Transverse "D" Cracking	Linear Feet
Longitudinal "D" Cracking	Linear Feet
Pumping	Highest Severity
Scaling, Map Cracking, Crazing	Severity Level
Longitudinal Cracking	Linear Feet
Longitudinal Joint Spalling	Linear Feet
Longitudinal Joint Faulting	No. of Areas
Punchouts	Number
Construction Joint Deterioration	Number
Reactive Aggregate	Percent of Area
Lane/Shoulder Dropoff	Mean Severity Found
Lane/Shoulder Separation	Mean Severity Found

- Please review your test data and summarize any additional distress parameters (from the FHWA list shown in Table 4) that you can obtain from your test data and equipment. We will compare the distress parameters you normally identify with our own visual field survey and those of other methods of long-term pavement monitoring.
- At your option, discuss other ways of collecting and processing distress survey data (for example, digitization and the use of video technology) that you have considered and list advantages/limitations of your normal procedure and other methods, if possible.

Traffic Control

Arrangements were made with the Texas SDHPT to allow the closing of portions of in-service highways during field testing. ARE Inc provided traffic control through an independent contractor. The principal traffic control was a truck with an arrow-board trailer that followed the high-speed equipment or stopped behind the equipment on the shoulder before and after the test when necessary. Traffic control was set up just prior to the arrival of the equipment at each site. The traffic lane was not closed during the field tests.

Participants Meeting

A short meeting was held the first day of testing between the participating teams for the various equipment/methods and the ARE Inc project team. The participating teams were briefed on project requirements and deliverables, and were given information packages containing test locations, maps, section numbers, route, and a testing schedule. The test plan was discussed and data submission requirements for each participating high-speed device was explained.

FIELD TESTING

Field testing of the instrumented survey vehicles was accomplished during July-September 1986 as described in Table 5 and Appendix B. The test routine was established according to discussions with the equipment operators in the first day's briefing. Table 5 also describes the period in which the visual distress surveys and mapping was accomplished.

The participants were instructed to operate their equipment using their standard operating procedures. This was done to insure that the devices were operated correctly. GERPHO and PASCO ROADRECON equipment were operated at night. Other surveys were performed during the daytime.

Due to time and funding constraints, field tests with the high-speed automated equipment were carried out within a four-day period. The test routine ran smoothly throughout the testing period with no major problems or delays experienced. The sequence used in this routine was:

- o Explained test locations and routing to the participating team.
- o Used a lead vehicle with ARE Inc staff members to guide the high-speed equipment to each test section and through the test.
- o Established traffic control on test section by using an arrow-board truck that always followed the high-speed equipment.
- o Began measurement of the pavement distresses by the equipment operators using standard operating procedures at the recommended speed.
- o Monitored field tests; an ARE Inc field engineer joined the operators in the equipment van for this purpose.
- o Observed and recorded testing time, speed, operation and any problems related to the test on the pavement section for each device.
- o Began repeat tests immediately after completion of the initial measurements, wherever required.
- o Performed replicate tests of selected sections on a different day after an ARE Inc staff member, in the lead vehicle, changed the section number appropriately.

Table 5. Details of actual dates of field tests and delivery of data and reports by the participants.

	TESTING DATES	INITIAL DATA/ REPORT RECEIVED	FURTHER DATA/ REPORT RECEIVED
MAPPING	08/04, 08/05, 08/07, 08/18, 08/20 - 08/22, 08/25	DISTRESS MAPS RECEIVED IMMEDIATELY AFTER TESTING	DATA REDUCTION COMPLETED BY 12/31/86
DETAILED SURVEYS (No CRCP)	08/11 - 08/14, 08/19	DATA SHEETS AND RATINGS RECEIVED BY 08/21/86	NO FURTHER DATA
DETAILED SURVEYS (CRCP Only)	09/12	DATA SHEETS RECEIVED 09/12/86	NO FURTHER DATA
AUTOMATED DATA LOGGER	08/04 - 08/06 09/05, 09/19, 10/10	HARD COPIES PRODUCED IMMEDIATELY AFTER TESTING	DATA SUMMARY AND RATINGS COMPLETED BY 01/06/87
GERPHO	07/17, 07/18, 07/20	PARTIAL DATA; INITIAL REPORT RECEIVED 07/26/86 *	FINAL REPORT WITH ALL PROCESSED DATA RECEIVED 08/22/86
PASCO ROADRECON	07/21, 07/22, 07/23	NO INITIAL DATA OR REPORT RECEIVED	ALL DATA AND FINAL REPORT RECEIVED 10/10/86
ARAN	09/04, 09/05, 09/07, 09/08	MEMO AND ALL PROCESSED DATA RECEIVED 09/11/86	INFORMATION ON DATA INTERPRETATION RECEIVED 10/17/86
LASER RST	09/08 - 09/11	DATA PROCESSED IN FIELD; HARD COPIES & EXPLANATION OF RAW FIELD DATA RECEIVED 09/12/86	INFORMATION ON DATA INTERPRETATION RECEIVED 09/19/86; FURTHER EXPLANATION RECEIVED 10/03/86

* NOTE: ALL DATA COULD NOT BE PROCESSED BECAUSE TIME WAS TAKEN TO TRAIN ARE INC STAFF ON GERPHO'S METHOD OF DATA COLLECTION.

There were a few environmentally related operating constraints during the field testing. The most critical condition was the presence of dry roads and no precipitation imminent. Other weather factors, such as sunshine, cloud cover, humidity, and wind, do not normally hinder distress survey measurements. To minimize test time, the repeat measurements over a test section were performed immediately after the initial measurements. The sequence in which the test sections were tested was not randomized due to practical time constraints. The test sections were tested in the order required to reduce travel time. Table 6 illustrates an overview of distress survey tests performed and data collected by each method or equipment.

DISTRESS SURVEY DATA

There are generally three major steps required to obtain distress survey reports for each method or equipment.

1. Field test or measurement.
2. Raw data collection.
3. Data interpretation
   a. On-board interpretation
   b. Office interpretation

Depending on the method or equipment, all three steps may be accomplished at the same time in the field, or it may require a significant amount of time between each step. A device or method can produce a final distress survey report in a very short time, but may contain inadequate information or may lack precision. Table 7 compares the field outputs and interpretation steps with respect to the methods and high-speed automated equipment tested in this study.

The Laser RST was the fastest among all of the methods and equipment. Final distress data reports were generated in the field using on-board computers. No other method or equipment made on-board interpretations. Manual mapping was the most time-consuming and labor-intensive method for both the field testing and the manual data reduction in the office. The

Table 6. A factorial presentation of all distress survey tests performed in this study.

TYPE AND CONDITION OF PAVEMENT SECTION

RIGID

DISTRESS SURVEY METHODS AND EQUIPMENT	GOOD				MOD.			POOR					
	R1	R2	101	R3	R4	R5	R6	R7	R7	R8	R8	105	R9
	I	I	T	I	I	I	I	I	R	I	R	T	I
MAPPING	√	√	*	√	√	√	√	√	*	√	*	*	√
DETAILED SURVEYS (NO CRCP)	*	*	*	*	√	*	*	√	*	*	*	*	*
DETAILED SURVEYS (CRCP ONLY)	√	√	√	√	*	√	√	*	*	√	*	√	√
AUTOMATED DATA LOGGER	√	√	√	√	√	√	√	√	*	√	*	√	√
GERPHO	√	√	*	√	√	√	√	√	ø	√	ø	*	√
PASCO ROADRECON	√	√	√	√	√	√	√	√	√	√	√	√	√
ARAN	√	√	√	√	√	√	√	√	√	√	√	√	√
LASER RST	√	√	√	√	√	√	√	√	√	√	√	√	√

FLEXIBLE

DISTRESS SURVEY METHODS AND EQUIPMENT	GOOD				MODERATE							POOR							
	F1	7	7	19	F4	100	41	41	200	55	55	4	4	44	44	201	56	56	300
	I	I	T	I	I	T	I	R	T	I	R	I	R	I	R	T	I	R	I
MAPPING	√	√	*	√	√	*	√	*	√	√	*	√	*	√	*	*	√	*	√
DETAILED SURVEYS (NO CRCP)	√	√	*	√	√	*	√	*	√	√	*	√	*	√	√	*	√	*	√
DETAILED SURVEYS (CRCP ONLY)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
AUTOMATED DATA LOGGER	√	√	√	√	√	√	√	*	√	√	*	√	*	√	*	√	√	*	√
GERPHO	√	√	ø	√	√	√	√	ø	ø	√	ø	√	ø	√	ø	*	√	ø	√
PASCO ROADRECON	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
ARAN	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
LASER RST	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√

COMPOSITE (AC OVER PCC)

DISTRESS SURVEY METHODS AND EQUIPMENT	GOOD			MOD	POOR					
	C1	C3	104	C8	C5	102	C7	C9	C9	103
	I	I	T	I	I	T	I	I	R	T
MAPPING	√	√	*	√	√	*	√	√	*	*
DETAILED SURVEYS (NO CRCP)	√	√	*	√	√	*	√	√	*	*
DETAILED SURVEYS (CRCP ONLY)	*	*	*	*	*	*	*	*	*	*
AUTOMATED DATA LOGGER	√	√	√	√	√	ø	√	√	*	√
GERPHO	√	√	*	√	√	*	√	√	ø	*
PASCO ROADRECON	√	√	√	√	√	√	√	√	√	√
ARAN	√	√	√	√	*	√	√	√	√	√
LASER RST	√	√	√	√	√	√	√	√	√	√

I - Initial Test
R - Repeat Test
T - Blind Replicate Test
√ - Data Completed
ø - Missing Data
* - Explanation given on Missing Data

Table 7. A comparison of distress data collection by the selected methods and equipment.

Method	Field Output	On-board Interpretation	Office Interpretation and Report
Manual Mapping	Distress Maps	None	Manually reduced data from distress maps.
Detailed Visual Survey, Manual Recording	Data Sheets for Paver (COPES data sheets are prepared for direct inputting into computer data files).	None	Manually computed pavement condition ratings (PAVER).
Detailed visual survey, automated data logging	Hard copy of data and computer-encoded microcassette.	None	Data summary & ratings
GERPHO	35-mm negative film	None	Final report including reduced distress data from film in French format and FHWA-LTM format, explanation of interpretation, sample paper prints of continuous photographing.
PASCO ROADRECON	35-mm negative film	None	o Final report including pavement condition indices & explanation of data interpretation. o Plots of cross profiles. o Paper prints of continuous photographing and cross profiles. o Paper chart of longitudinal profiling. o Photos taken in field.
ARAN	Raw surface data on 5-1/4-inch floppy disk (IBM compatible) and VHS videotapes.	None	Data summary including ratings and plots of indices.
Laser RST	Raw surface data in dBASE III format on 5-1/4-inch floppy disk (IBM compatible).	Final report summarizing all data collected.	Report to answer questions on data interpretation.

detailed visual survey procedures were significantly slower than other high-speed devices because these detailed visual surveys were performed manually at walking speed. GERPHO, PASCO ROADRECON and ARAN were comparable in the time taken for field measurements. However, ARAN was capable of providing final data reports within a few days in Austin. Videotapes were sent back to Austin at a later date.

Among all high-speed devices, both GERPHO and PASCO ROADRECON used 35-mm continuous film to record a permanent image of the pavement surface using an artificial light source. Both required development of the film and office data interpretation. GERPHO developed the film in Austin and provided partial data reports within a few days using a portable office data interpretation station and a microcomputer. PASCO sent their film to their headquarters in Japan for processing and data interpretation and submitted their data and reports in approximately two and one half months. One ARE Inc staff member observed their office procedures in New Jersey.

GERPHO is the only equipment that is not capable of measuring rut depth in its present design. However, it was the only participant that 1) provided training and considerable time to the ARE Inc staff members to perform independent office data interpretation in Austin, and 2) adapted their software to produce distress data reports using the FHWA list of distress items (Table 4) and U.S. units of measurements.

Comparison of Distresses

An example of the data output of each method is included in Appendix B. The definitions used for describing the extent of distresses and distress types considered by each method are not uniform across all methods. Differences exist even among the three manual, labor-intensive methods. These are explained in Tables 8, 9, and 10.

Table 8. Typical flexible and composite pavement distresses considered by each method.

DISTRESS	MAPPING	DETAILED SURVEY	AUTOMATED DATA LOGGER	GERPHO	PASCO	ARAN	LASER RST
ALLIGATOR/ FATIGUE CRACKING	SQUARE FEET	SQUARE FEET	PERCENTAGE OF AREA (RANGE)	SQUARE FEET	INCLUDED IN CRACK RATIO	% OF AREA (RANGE)	% OF AREA (RANGE)
RAVELING	SQUARE FEET	*	LOCAL/ THROUGHOUT	SQUARE FEET	*	% OF AREA (RANGE)	*
BLEEDING	SQUARE FEET	SQUARE FEET	LOCAL/ THROUGHOUT	SQUARE FEET	*	% OF AREA (RANGE)	*
BLOCK CRACKING	SQUARE FEET	SQUARE FEET	PERCENTAGE OF AREA (RANGE)	SQUARE FEET	INCLUDED IN CRACK RATIO (PERCEN-TAGE OF SURFACE AREA)	*	*
LONGITUDINAL CRACKING	LINEAR FEET	LINEAR FEET	NUMBER	LINEAR FEET		LINEAR FEET (RANGE)	WIDTH (RANGE)
TRANSVERSE CRACKING	LINEAR FEET		NUMBER (RANGE)	LINEAR FEET		CRACK SPACING (RANGE)	NUMBER; WIDTH& DEPTH (RANGE IN mm)
POTHOLES/ POTHOLE PATCHING	NUMBER (POTHOLES)/ SQ. FT. (PATCHING)	NUMBER (POTHOLES)/ SQ. FT. (PATCHING)	NUMBER (RANGE)	NUMBER	INCLUDED IN PATCH RATIO	NUMBER OF POTHOLES	*
REFLECTION CRACKING	LINEAR FEET	LINEAR FEET (JOINT REFLECTION)	*	LINEAR FEET	INCLUDED IN CRACK RATIO	*	*
LANE/ SHOULDER DROPOFF	LINEAR FEET	LINEAR FEET	*	*	*	*	SEVERITY
LANE/ SHOULDER SEPARATION	*	*	*	MEAN SEVERITY	*	*	*
RUTTING	SQUARE FEET	SQUARE FEET	LOCAL/ THROUGHOUT	*	MAX. AND MEAN DEPTH (mm)	MEAN DEPTH (INCHES)	DEPTH (mm)

* Distress not considered.

Table 9. Typical JRCP pavement distresses considered by each method.

DISTRESS	MAPPING	DETAILED SURVEY	AUTOMATED DATA LOGGER	GERPHO	PASCO	ARAN	LASER RST
BLOWUPS	*	NUMBER AFFECTED SLABS	NUMBER (RANGE)	NUMBER	*	*	*
TRANSVERSE JOINT SPALLING	NUMBER (OF SPALLED JOINTS AND CRACKS)	NUMBER OF AFFECTED SLABS (CORNER SPALLING)	*	NUMBER OF JOINTS	*	PERCEN-TAGE (RANGE)	*
LONGITUDINAL JOINT SPALLING			*	NUMBER OF JOINTS	*		*
JOINT LOAD TRANSFER ASSOCIATED DETERIORATION	*	*	*	NUMBER OF JOINTS	*	*	*
PUMPING & WATER BLEEDING	NUMBER	NUMBER AFFECTED SLABS	HIGHEST SEVERITY	HIGHEST SEVERITY FOUND	*	*	*
LONGITUDINAL "D" CRACKING	*	NUMBER OF AFFECTED SLABS	NUMBER (RANGE)	LINEAR FEET	INCLUDED IN CRACK RATIO (PERCEN-TAGE OF SURFACE AREA)	*	*
TRANSVERSE "D" CRACKING	*			LINEAR FEET		*	*
LONGITUDINAL CRACKING	LINEAR FEET	NUMBER OF AFFECTED SLABS	NUMBER (RANGE)	LINEAR FEET		LINEAR FEET (RANGE)	WIDTH (RANGE)
TRANSVERSE CRACKING	*		NUMBER (RANGE)	LINEAR FEET		CRACK SPACING (RANGE)	NUMBER; WIDTH & DEPTH (RANGE IN mm)
LANE/ SHOULDER DROPOFF	LINEAR FEET	*	*	*	*	*	SEVERITY
LANE/ SHOULDER SEPARATION	LINEAR FEET	*	MEAN SEVERITY	MEAN SEVERITY FOUND	*	*	*
CORNER BREAKS	NUMBER	NUMBER AFFECTED SLABS	*	NUMBER	*	NUMBER	*
REACTIVE AGGREGATE	*	*	*	PERCEN-TAGE OF AREA	*	*	*
JOINT FAULTING	*	NUMBER AFFECTED SLABS	NUMBER (RANGE)	*	*	*	*

* Distress not considered.

Table 10. Typical CRCP pavement distresses considered by each method.

<table>
<tr><th>DISTRESS</th><th>MAPPING</th><th>DETAILED SURVEY</th><th>AUTOMATED DATA LOGGER</th><th>GERPHO</th><th>PASCO</th><th>ARAN</th><th>LASER RST</th></tr>
<tr><td>TRANSVERSE CRACK SPALLING</td><td rowspan="2">NUMBER (OF SPALLED JOINTS AND CRACKS)</td><td>*</td><td>*</td><td>LINEAR FEET</td><td>*</td><td rowspan="2">PERCENTAGE (RANGE)</td><td>*</td></tr>
<tr><td>LONGITUDINAL CRACK SPALLING</td><td>*</td><td>*</td><td>LINEAR FEET</td><td>*</td><td>*</td></tr>
<tr><td>TRANSVERSE "D" CRACKING</td><td>*</td><td rowspan="2">LINEAR FEET</td><td rowspan="2">NUMBER (RANGE)</td><td>LINEAR FEET</td><td rowspan="2">INCLUDED IN CRACK RATIO (% OF SURFACE AREA)</td><td>*</td><td>*</td></tr>
<tr><td>LONGITUDINAL "D" CRACKING</td><td>*</td><td>LINEAR FEET</td><td>*</td><td>*</td></tr>
<tr><td>PUMPING</td><td>NUMBER</td><td>HIGHEST SEVERITY</td><td>HIGHEST SEVERITY</td><td>HIGHEST SEVERITY</td><td>*</td><td>*</td><td>*</td></tr>
<tr><td>SCALING, MAP CRACKING, CRAZING</td><td>% OF SURFACE AREA</td><td>HIGHEST SEVERITY</td><td>HIGHEST SEVERITY</td><td>SEVERITY</td><td>*</td><td>PERCENTAGE (RANGE)</td><td>*</td></tr>
<tr><td>LONGITUDINAL CRACKING</td><td>LINEAR FEET</td><td>LINEAR FEET</td><td>NUMBER (RANGE)</td><td>LINEAR FEET</td><td>INCLUDED IN CRACK RATIO</td><td>LINEAR FT. (RANGE)</td><td>*</td></tr>
<tr><td>LONGITUDINAL JOINT SPALLING</td><td>INCLUDED W/ CRACK SPALLING</td><td>NUMBER OF JOINTS</td><td>*</td><td>LINEAR FEET</td><td>*</td><td>INCLUDED WITH SPALLING</td><td>*</td></tr>
<tr><td>LONGITUDINAL JOINT FAULTING</td><td>*</td><td>YES (IF ≥ 0.5 INCH) OR NO</td><td>NUMBER (RANGE)</td><td>*</td><td>*</td><td>*</td><td>*</td></tr>
<tr><td>PUNCHOUTS</td><td>NUMBER</td><td>NUMBER</td><td>NUMBER (RANGE)</td><td>NUMBER</td><td>*</td><td>*</td><td>*</td></tr>
<tr><td>CONSTRUCTION JOINT DETERIORATION</td><td>NUMBER</td><td>NUMBER</td><td>NUMBER (RANGE)</td><td>NUMBER</td><td>*</td><td>*</td><td>*</td></tr>
<tr><td>REACTIVE AGGREGATE</td><td>*</td><td>% OF AREA</td><td>*</td><td>% OF AREA</td><td>*</td><td>*</td><td>*</td></tr>
<tr><td>LANE/ SHOULDER DROPOFF</td><td>LINEAR FEET</td><td>*</td><td>*</td><td>*</td><td>*</td><td>*</td><td>*</td></tr>
<tr><td>LANE/ SHOULDER SEPARATION</td><td>LINEAR FEET</td><td>MEAN SEVERITY</td><td>MEAN SEVERITY</td><td>MEAN SEVERITY</td><td>*</td><td>*</td><td>*</td></tr>
</table>

* Distress not considered.

CHAPTER 5. DISTRESS DATA ANALYSIS

A vast amount of data resulted from the distress surveys as seven different methods or devices surveyed twenty-five different pavement test sections. The distresses that were reported by each method and device on flexible and composite, continuously reinforced concrete, and jointed reinforced concrete pavement test sections are listed in Tables 11, 12, and 13 respectively.

Due to time and budget constraints, each method or device reported distresses according to each method's or each manufacturer's standard procedure. Thus, the methods did not report all of the same distresses and the distresses that were reported were in different formats. For example, the extent of rutting on flexible pavements was reported in square feet by several methods while rut depth (in millimeters or inches) was reported by several other methods.

Because of the large amount and nonuniformity of collected data, several of the reported distresses were selected for the data analysis. The selected distresses were ones predominantly found throughout the test sections and reported by most or all of the methods and devices. Flexible pavement distresses that were selected included: alligator cracking, longitudinal cracking, transverse cracking, potholes/patching, and rutting. Distresses selected for rigid pavement test sections included transverse cracking and map cracking/scaling/crazing. For composite pavement test sections, linear cracking was selected. Linear cracking included any transverse, longitudinal, and joint reflective cracking. Linear cracking was chosen for composite pavements as several methods combined different types of cracking. A detailed description of the distresses reported to be found on each pavement test section is presented in Appendix C.

Table 11. Distresses reported to be found on flexible and composite pavement test sections.

	Mapping	Detailed Survey	Automated Data Logger	GERPHO	PASCO	ARAN	Laser RST
Alligator Cracking	x	x	x	x	*	x	x
Bleeding	x	x	x	x		x	
Block Cracking	x	x	x	x	*		
Bumps/Sags		x					
Cracking Ratio					x		
Distortion						x	
Drainage			x				x
Edge Cracking/ Deterioration	x	x	x		*	x	
Lane/Shoulder Dropoff	x	x					x
Longitudinal Cracking	x	x	x	x	*	x	x
Longitudinal Profile					x		
Map Cracking						x	
Pavement Condition Index		x			x	x	
Potholes/Patching	x	x	x	x	x	x	
Pumping	x			x			
Random Cracking							x
Raveling/Weathering	x	x	x	x		x	
Reflection Cracking/ Joint Reflection	x	x		x	*		
Rutting	x	x	x		x	x	x
Shoulder Condition			x				x
Slippage Cracking		x					
Transverse Cracking	x	x	x	x	*	x	x

* Included in Cracking Ratio.

Table 12. Distresses reported to be found on continuously reinforced concrete pavement test sections.

	Mapping	Detailed Survey	Automated Data Logger	GERPHO	PASCO	ARAN	Laser RST
Construction Joint Distress			x				
Cracking Ratio					x		
Depression		x	x				
Lane/Shoulder Dropoff							x
Lane/Shoulder Separation		x	x	x			
Longitudinal Cracks	x	x	x	x	*	x	
Pavement Condition Index					x	x	
Popouts	x						
Potholes/Patching	x	x	x	x		x	
Pumping/Bleeding	x	x	x	x			
Punchouts	x	x	x				
Rut Depth						x	x
Scaling/Map Cracking/Crazing	x	x	x	x	*		
Shoulder Condition							x
Spalling		x		x		x	
Swell		x					
Transverse Cracking	x	x	x	x	*	x	x

* Included in Cracking Ratio.

Table 13. Distresses reported to be found on jointed reinforced concrete pavement test sections.

	Mapping	Detailed Survey	Automated Data Logger	GERPHO	PASCO	ARAN	Laser RST
Coarse Aggregate Loss						x	
Corner Break		x	x	x			
Cracking Ratio					x		
Depression			x				
Drainage							x
Durability ("D") Cracking			x				
Joint Seal Damage		x				x	
Lane/Shoulder Dropoff		x					x
Lane/Shoulder Joint Separation			x				
Patch Deterioration			x				
Pavement Condition Index		x			x	x	
Popouts	x						
Potholes				x		x	
Pumping/Bleeding			x				
Rut Depth						x	x
Scaling/Map Cracking/ Crazing	x		x	x	*		
Shoulder Condition							x
Spalling	x	x		x		x	
Transverse/Diagonal Cracks				x	*		x

* Included in Cracking Ratio.

FLEXIBLE PAVEMENT TEST SECTIONS

Distress surveys were conducted on ten different flexible test sections (F1, 7, 19, F4, 41, 55, 4, 44, 56, and 300). Five sections were repeated immediately following the first survey (41, 55, 4, 44, and 56) and four sections were replicated several days later (7, 100-F4, 200-41, and 201-44). The identification of replicate sections 100 (F4), 200 (41), and 201 (44) was not revealed until the data analyses were completed. The numbering of Section 7 could not be changed prior to the replicate run, thus the replicate run was also identified as 7. Mapping and the manual detailed visual survey was done for only the initial runs, due to time constraints. The automated data logger completed replicate runs as well as initial runs. PASCO, ARAN, and the Laser RST completed all initial, repeat, and replicate runs. GERPHO filmed all initial, repeat, and replicate sections. However, the distresses were not reduced on the repeat and replicate runs (except for Section 100-F4) because the films on the reviewing machine were found to be identical (Ref 31).

Table 14 summarizes the procedures used to measure and report the selected distresses. Table 15 presents a comparison of the alligator cracking found by each method or device on the 1000-foot (305 m) flexible test sections. For the method of mapping, two 100-foot (30.5 m) subsections were chosen at random to be mapped. After reduction of the data, the extent of distresses in each subsection was added together and the results multiplied by five to obtain an estimate for each 1000-foot (305 m) test section. Tables 16, 17, 18, and 19 compare the longitudinal cracking, transverse cracking, potholes/patching, and rutting reported by each method or device and are presented in Appendix C. The following results are based on a comparison of the data presented in the tables.

Alligator Cracking

Over half of ten different flexible pavement sections had significant amounts of alligator cracking. Each method except PASCO identified alligator cracking in square feet (mapping, manual survey, GERPHO) or as a percentage (data logger, ARAN, Laser RST). PASCO combined all types of

Table 14. Measurement of distresses reported on flexible pavement test sections by each method or device.

Method or Device	Cracking	Potholes/Patching	Rutting
Mapping	Alligator cracking measured in square feet, severity level based on spalling. Longitudinal and transverse cracking each measured (separately) in linear feet, severity levels based on spalling, faulting, or crack width.	Quantity of potholes reported. Patch measured in square feet. Severity levels based on condition (all potholes considered "poor").	Measured in square feet. Mean rut depth determines severity level.
Detailed Visual Survey, Manual	Alligator cracking measured in square feet, severity level based on spalling. Longitudinal and transverse cracking combined & measured in linear feet, severity levels based on crack width and spalling.	Quantity of potholes is recorded. Severity level determined by maximum depth. Patching reported in square feet. Severity level based on condition & ride quality.	Measured in square feet. Mean rut depth determines severity level.
Detailed Visual Survey, Automated Data Logger	Alligator cracking reported as (estimated) percentage of surface area, severity levels based on crack width spalling. Quantity of transverse and longitudinal cracks reported (separately) as equivalent full-width or full-length of section, severity levels based on crack width.	Combined count of potholes & patches given. All potholes considered "poor", patches are rated poor or good based on condition.	Reported as occurring throughout the section or in localized areas. Severity levels are based on an estimate of rut depth.

Table 14. Measurement of distresses reported on flexible pavement test sections by each method or device (continued).

Method or Device	Cracking	Potholes/Patching	Rutting
GERPHO	Alligator cracking reported in square feet. Longitudinal & transverse cracking each reported in linear feet. (Negative film used to identify).	Quantity of potholes reported. Patching reported in square meters. (Negative film used to identify.	Not measured.
PASCO	Alligator cracking area, linear cracking area, & patching area combined and reported as a percentage of observed area (Crack Ratio).(Positive, negative film used).	Area of emergent repair reported as a percentage of observed area (Patching Ratio).(Positive, negative film used).	Cross profile measured (using digitizer) from negative film every 50 ft. Maximum & mean rut depths (mm) reported for each section.
ARAN	Alligator cracking reported as percentage of surface area, severity level based on spalling. Longitudinal cracking reported as linear feet, severity level based on crack width. Transverse cracking reported as crack spacing/sample, severity level based on crack width. All cracking measured by "windshield" survey, reported in range of values.	Quantity of potholes reported (through "windshield" survey). Severity level based on width and depth. Patching not measured.	Measures rut depth objectively with ultrasonic sensors. Average rut depth (inches) is reported for both left & right wheelpaths.
Laser RST	Alligator & longitudinal cracking reported subjectively through "windshield" survey. Quantity of transverse cracks measured objectively with lasers.	Not measured.	Measures (objectively, with lasers) deepest rut every 10 cm. An average (of those deepest measured) is reported (mm).

Table 15. Comparison of reported alligator cracking for flexible pavement sections.

SECTION	DISTRESS *	MAPPING (Square Feet)	DETAILED VISUAL SURVEY		GERPHO (Square Feet)	PASCO** (Crack Ratio %)	ARAN (Percent of Area)	LASER RST (Percent of Area)
			Manual (Square Feet)	Automated Data Logger (Percent of Area)				
F1	Severity	Low	Low	Low	0	--	0	--
	Extent	110	7	1 - 10% (120 - 1200)	0	1.1	0	0
7 (Initial)	Severity	Low	Low	Low	Low	--	0	--
	Extent	60	110	1 - 10% (120 - 1200)	21	2.2	0	0
7 (Replicate)	Severity	--	--	Low	--	--	Low	--
	Extent	--	--	1 - 10% (120 - 1200)	--	2.1	10% (1200)	0
19	Severity	0	0	0	Low	--	0	--
	Extent	0	0	0	168	0.0	0	0
F4	Severity	Low	Low	Low	Low	--	Low, Mod	--
	Extent	1660	339	11 - 20% (1320 - 2400)	288	6.6	10% (1200)	0
100 (Replicate of F4)	Severity	--	--	Low	Low	--	Low, Mod	--
	Extent	--	--	11 - 20% (1320 - 2400)	149	6.5	10% (1200)	0
41 (Initial)	Severity	0	Low	Low	Low	--	0	--
	Extent	0	612	1 - 10% (100 - 1000)	1557	0.0	0	0
41 (Repeat)	Severity	--	--	--	--	--	0	--
	Extent	--	--	--	--	0.0	0	0
200 (Replicate of 41)	Severity	--	--	0	--	--	0	--
	Extent	--	--	0	--	0.0	0	0

*Based on the standard procedures used by each device or method. (Number in parenthesis is distress in square feet).

**Includes all cracking and patching.

Note: 1 square foot = 0.0929 square meter.

Table 15. Comparison of reported alligator cracking for flexible pavement sections (continued).

SECTION	DISTRESS *	MAPPING (Square Feet)	DETAILED VISUAL SURVEY Manual (Square Feet)	DETAILED VISUAL SURVEY Automated Data Logger (Percent of Area)	GERPHO (Square Feet)	PASCO** (Crack Ratio %)	ARAN (Percent of Area)	LASER RST (Percent of Area)
55 (Initial)	Severity	0	0	0	0	--	0	--
	Extent	0	0	0	0	0.9	0	0
55 (Repeat)	Severity	--	--	--	--	--	0	--
	Extent	--	--	--	--	0.9	0	0
4 (Initial)	Severity	Low	Low, Moderate	Low, Moderate	Low	--	0	--
	Extent	275	472	51-80% (5610-8800)	580	6.2	0	0
4 (Repeat)	Severity	--	--	--	--	--	0	--
	Extent	--	--	--	--	6.0	0	0
44 (Initial)	Severity	Low	Low, Moderate	Low	Low	--	Low	--
	Extent	1310	1195	1-10% (100-1000)	934	5.4	10% (1000)	0
44 (Repeat)	Severity	--	--	--	--	--	Low	--
	Extent	--	--	--	--	5.6	10% (1000)	0
201 (Replicate of 44)	Severity	--	--	Low, Moderate	--	--	Low	--
	Extent	--	--	1 - 10% (100 - 1000)	--	5.4	10% (1000)	0
56 (Initial)	Severity	Low, Moderate	Low, High, Moderate	Moderate	Low	--	Low, Mod., High	--
	Extent	5400	3250	81-100% (8100-10000)	7271	72.6	20-40% (2000-4000)	Over 33% (3300)
56 (Repeat)	Severity	--	--	--	--	--	Low, High	--
	Extent	--	--	--	--	72.4	20-40% (2000-4000)	Over 33% (3300)
300	Severity	0	Moderate	0	Low	--	0	--
	Extent	0	25	0	171	2.0	0	0

*Based on the standard procedures used by each device or method. (Number in parenthesis is distress in square feet).

**Includes all cracking and patching.

Note: 1 square foot = 0.0929 square meter.

cracking and patching and reported a crack ratio. The sections identified by each method as having alligator cracking were as follows:

Method	Sections (amount of alligator cracking in decreasing order as reported by each method)
Mapping	56, F4, 44, 4, F1, 7
Manual Survey	56, 44, 41, 4, F4, 7, 300, F1
Automated Survey	56, 4, F4, 44, 41, 7, F1
GERPHO	56, 41, 44, 4, F4, 19, 7
PASCO	56, F4, 4, 44, 7, 300, F1, 55
ARAN	56, 44, F4, 7
Laser RST	56

While examining alligator cracking, the following keypoints were found.

- o The automated data logger estimated alligator cracking as a percentage of the total area rather than measuring the actual area.
- o GERPHO identified alligator cracking in Section 19. None of the other methods or devices reported this distress and the section was carefully rechecked and no alligator cracking was found.
- o PASCO did not report alligator cracking as a separate distress, but, rather included it in a crack ratio with all types of cracking and patching.
- o ARAN estimated the percentage of alligator cracking through a "windshield" survey and could not identify all sections that did have this distress.

- The Laser RST reported alligator cracking in only one flexible section. It identified this distress through a "windshield" survey and was capable only of noting whether the distress covered greater or less than 33 percent of the area.

Longitudinal Cracking

Most of the ten different flexible pavement sections had longitudinal cracking. All of the methods identified longitudinal cracking in some manner. Mapping, manual survey, and GERPHO reported in linear feet. The automated data logger reported in equivalent full-section length cracks. ARAN reported as a percentage and the Laser RST noted if the width was greater or less than 0.5 inches (13 mm). PASCO, as explained earlier, reported a crack ratio. The sections identified as having this cracking by each method or device were as follows:

Method	Sections (amount of longitudinal cracking in decreasing order as reported by each method)
Mapping	4, 55, 41, 44, 56, F4, F1, 300, 7
Manual Survey	55, F1, 300, 4, F4
Automated Survey	56, 44, 4, F1, 41
GERPHO	4, 41, 44, 7, F1, 56, 300, F4, 19, 55
PASCO	56, F4, 4, 44, 7, 300, F1, 55
ARAN	56, 44, 4, 41, 7, F1
Laser RST	56, 4, 44, 41, 300

The following limitations of each method or device in reporting longitudinal cracking were found.

- The manual survey method combined longitudinal and transverse cracking. It did not report the amount of each distress separately.

- The automated data logger reported longitudinal cracks only in 1000-ft (305 m) increments (the section length). Thus, small amounts of longitudinal cracking would be reported as zero.

- PASCO combined longitudinal cracking with all other types of cracking and patching and reported only a crack ratio.

- ARAN estimated longitudinal cracking and reported only within a range. In sections where longitudinal cracking existed in small amounts, ARAN often reported no cracking (Sections F4 and 55). In addition, ARAN's measurements were not repeatable (Sections 7, 41, 56).

- Longitudinal cracks were identified by the Laser RST through a "windshield" survey and were reported only as having a width greater or less than 0.5 inches (13 mm). The extent of longitudinal cracking was not reported.

Transverse Cracking

Over half of the ten different flexible sections had transverse cracking. All methods reported transverse cracking in the same manner as longitudinal cracks, except for the Laser RST which objectively counted transverse cracks. The sections identified as having transverse cracks by the various methods or devices were as follows:

Method	Sections (amount of transverse cracking in decreasing order as reported by each method)
Mapping	4, 44, 300, F4, 55
Manual Survey	55, F1, 300, 4, F4
Automated Survey	300, 44, F4, F1, 7
GERPHO	44, 55, F4, 7, F1
PASCO	56, F4, 4, 44, 7, 300, F1, 55

ARAN	F1, F4
Laser RST	56, 7, 41, F4, F1, 55, 44

The following limitations of each method or device in reporting transverse cracking were found.

- The manual survey method combined longitudinal and transverse cracking. It did not report separate values for these distresses.

- Transverse cracks were reported by the data logger as equivalent full-width cracks and the number was given only as a range of values.

- PASCO did not report transverse cracking separately. It was included with all cracking and patching in a section crack ratio.

- ARAN reported transverse cracking only in a range of values.

- The Laser RST measured transverse cracks objectively, yet, on Section 300, the visual methods and GERPHO all reported transverse cracking, and the Laser RST reported no cracking. Also, the Laser RST measurements were not always repeatable. On Section 41, 15 cracks were reported on the initial test, 3 on the repeat test, and 64 on the replicate test. Another limitation found was that alligator cracking was included in the transverse crack count. On sections with alligator cracking, there was no way to distinguish how much of the transverse crack count was alligator cracking and how much was actually transverse cracking. Other methods did not report transverse cracks on Section 41.

Potholes/Patching

About half of the flexible sections had potholes or patching. Mapping and the manual survey method reported potholes (quantity of) and patching (in square feet). The automated data logger combined patching and potholes in one category and reported these distresses as one quantity. GERPHO reported patching (in square meters) and potholes/pothole patching (quantity). ARAN reported potholes (quantity). Laser RST reported neither potholes nor patching. PASCO reported a patching ratio, which included areas of emergent repair. The sections identified as having potholes/patching were as follows:

Method	Sections (amount of potholes/patching in decreasing order as reported by each method)
Mapping	7, 44, 55, F4, 56
Manual Survey	7, 56, 44, 55, F4, 300, 4
Automated Survey	56, 4, 55, F4, 300
GERPHO	56, 44, 55, 4, 41, F4, 300
PASCO	55, 56, 44
ARAN	56, 4, 55, 7
Laser RST	

In identifying potholes and patches, the following limitations were found.

- The automated data logger combined potholes and patching. These distresses were not reported separately.

- GERPHO did not report all of the patching that was identified by other methods (Section 7, F4).

- PASCO included patching in the cracking ratio. PASCO's patching ratio included only areas of emergent repair.

- ARAN did not report patching. Potholes were counted, but were not always repeatable (on Section 56, 30 potholes were counted on the initial run and 10 potholes were counted on the repeat run).

- The Laser RST did not report patching or potholes.

Rutting

Most of the flexible test sections had rutting. Mapping and the manual survey reported rutting in square feet. The automated survey reported rutting as localized or throughout the section. GERPHO did not report rutting. PASCO reported the maximum rut depth (samples taken every 50 feet or 15.2 m) for the section. ARAN reported average rut depths for each wheelpath. The maximum depth (of these two average values) was shown in the tables. The Laser RST reported a rut depth that was the average value of recorded maximum values taken every 10 centimeters.

Method	Sections (amount of rutting in decreasing order as reported by each method)
Mapping	56, 4, 44
Manual Survey	56, 4, 41, 55, 7, 300
Automated Survey	56, 4, 41, 44, 55, 7, 300, F4, 19
GERPHO	
PASCO	56, 44, 300, 41, 4, 55, 19, 7
ARAN	56, 44, 300, 19, F4, F1, 4, 7, 55, 41
Laser RST	56, 44, 41, 4, 55, 300, 19, F4, F1, 7

In identifying rutting, the following limitations were found.

- Mapping measured the extent of rutting but did not report the rut depth (although rut depth was used to define the severity level). Also, it should be noted that the mappers did not measure rutting in Sections 7 and 41.

- The manual survey method also measured the rut depth (used to define the severity level) but reported only the extent.

- The data logger estimated rutting and reported it only as localized or throughout.

- GERPHO did not measure rutting.

- The ARAN and Laser RST rut depth measurements were lower than those measured manually. As explained in Appendix C, this may be due to the different measurement intervals and sampling rates.

RIGID PAVEMENT TEST SECTIONS

Distress surveys were conducted on nine different rigid test sections (R1, R2, R3, R4, R5, R6, R7, R8, R9). Sections R4 and R7 were JRCP and the rest were CRCP. Two sections were repeated immediately following the first survey (R7, R8) and two sections were replicated on a different day (R2-101, R8-105). The identification of the replicate sections was not revealed until the data analyses were completed. Due to time constraints, mapping was completed only for two random 100-foot (30.5 m) subsections. After reduction of data, the extent of distresses in each subsection was added together and results multiplied by five to obtain an estimate for each 1000-foot test section. The detailed visual surveys were completed for initial and replicate runs (no repeat tests). PASCO, ARAN, and Laser RST completed all initial, repeat, and replicate runs. GERPHO filmed all initial, repeat, and replicate runs. However, the distresses on the repeat and replicate runs were not reduced because the films on the reviewing machine were found to be identical (Ref 31).

Table 20 summarizes the procedures used to measure and report the selected distresses. Table 21 presents a comparison of transverse cracking reported by each method or device on the rigid test sections. A comparison of the reported map cracking/scaling/crazing is presented in Table 22 in Appendix C. The following results are based on a comparison of the data presented in the tables.

Transverse Cracking

All of the CRCP test sections had significant amounts of transverse cracking. All of the methods, except PASCO and ARAN, reported the quantity of transverse cracks. PASCO combined all types of cracking and

Table 20. Measurement of distresses reported on rigid pavement test sections by each method or device.

Method or Device	Transverse Cracking	Map Cracking/Scaling/ Crazing
Mapping	Quantity of transverse cracks reported. Severity level based on faulting, steel rupture, and spalling.	Scaling, map cracking, & crazing reported as percentage of affected area. Severity level based on amount of scaling present.
Detailed Visual Survey, Manual	Quantity of transverse cracks reported. Severity level based on faulting and spalling.	Scaling and map cracking or crazing rated as highest severity level found. Severity level based on amount of scaling.
Detailed Visual Survey, Automated Data Logger	Quantity of transverse cracks reported (a range). Severity level based on crack width.	Scaling, map cracking, or crazing rated as highest severity level found. Severity level based on scaling.
GERPHO	Quantity of transverse cracks reported.	Severity level of scaling, map cracking, crazing reported.
PASCO	All linear cracking & area of emergent repair combined for crack ratio.	Not measured.
ARAN	Crack spacing (range) noted. Severity level based on crack width, spalling, & faulting.	Scaling only reported as percentage (in range) of area. Severity level based on disintegration of surface.
Laser RST	Quantity of transverse cracks measured objectively with lasers.	Not measured.

Table 21. Comparison of reported transverse cracking for rigid pavement sections.

SECTION	DISTRESS *	MAPPING (Quantity)	DETAILED VISUAL SURVEY		GERPHO (Quantity)	PASCO** (Crack Ratio, %)	ARAN (Crack Spacing, feet)	LASER RST (Quantity)
			Manual (Quantity)	Automated Data Logger (Quantity)				
R1 (CRCP)	Severity	Low	Low,Mod.	Low,Mod.	--	--	Low	--
	Extent	270	259	>40	154	52.0	20-50	--
R2 (Initial) (CRCP)	Severity	Low	Low,Mod., High	Low,Mod., High	--	--	Low	--
	Extent	270	258	>40	115	32.1	0-20	--
101 (Replicate of R2)	Severity	--	Low,Mod., High	Low,Mod., High	--	--	Low	--
	Extent	--	255	>40	--	31.8	>250	--
R3 (CRCP)	Severity	Low, Moderate	Low,Mod., High	Low,Mod., High	--	--	Low	--
	Extent	400	336	>40	283	91.9	0-20	119
R4 (JRCP)	Severity	0	0	0	--	--	0	--
	Extent	0	0	0	0	0.3	0	0
R5 (CRCP)	Severity	Low, Moderate	Low, Moderate	Low, Moderate	--	--	Low	--
	Extent	415	367	>40	312	101.0	0-20	134
R6 (CRCP)	Severity	Low, Moderate	Low,Mod., High	Low,Mod., High	--	--	Low	--
	Extent	385	368	>40	297	95.6	0-20	125
R7 (Initial) (JRCP)	Severity	0	0	0	--	--	0	--
	Extent	0	0	0	0	0.6	0	46
R7 (Repeat)	Severity	--	--	--	--	--	0	--
	Extent	--	--	--	--	0.7	0	55

* Based on the standard procedures used by each device or method.

** Includes all types of linear cracking and areas of emergent repair.

Note: 1 foot = 0.3048 m.

Table 21. Comparison of reported transverse cracking for rigid pavement sections (continued).

SECTION	DISTRESS *	MAPPING (Quantity)	DETAILED VISUAL SURVEY Manual (Quantity)	DETAILED VISUAL SURVEY Automated Data Logger (Quantity)	GERPHO (Quantity)	PASCO** (Crack Ratio, %)	ARAN (Crack Spacing, feet)	LASER RST (Quantity)
R8 (Initial) (CRCP)	Severity	Low, Moderate	Low, Mod., High	Low, Mod., High	--	--	Low	--
	Extent	320	325	>40	272	83.7	0-20	98
R8 (Repeat)	Severity	--	--	--	--	--	Low	--
	Extent	--	--	--	--	83.5	0-20	107
105 (Replicate of R8)	Severity	--	Low, Mod., High	Low, Mod., High	--	--	Low	--
	Extent	--	318	>40	--	101.0	0-20	--
R9 (CRCP)	Severity	Low, Moderate	Low Moderate	Low, Moderate	--	--	Low	--
	Extent	425	354	>40	296	94.0	0-20	153

* Based on the standard procedures used by each device or method.

** Includes all types of linear cracking and areas of emergent repair.

Note: 1 foot = 0.3048 m

patching and reported a crack ratio. ARAN reported a range of crack spacing. The sections identified by each method as having transverse cracks were as follows:

Method	Sections (amount of transverse cracks in decreasing order as reported by each method)
Mapping	R9, R5, R3, R6, R8, R2, R1
Manual Survey	R6, R5, R9, R8, R3, R1, R2
Automated Survey	R8, R6, R3, R2, R9, R5, R1
GERPHO	R5, R6, R9, R3, R8, R1, R2
PASCO	R5, R6, R9, R3, R8, R1, R2
ARAN	R9, R8, R6, R5, R3, R1, R2
Laser RST	R9, R5, R6, R3, R8, R7

In reporting transverse cracking, the following limitations were found:

- o The automated data logger reported quantity only as a range.

- o GERPHO did not report severity levels. In addition, the quantity of cracks reported was about 20 percent lower than the quantity reported by mapping and the manual detailed survey.

- o PASCO reported a section crack ratio, which included all types of cracking and patching. Transverse cracking was not reported as a separate distress.

- o ARAN reported crack spacing only as a range. Also, poor repeatability was shown for Section R2 (crack spacing of 0 to 20 feet (0 to 6.1 m) for the initial test and greater than 250 feet (76.2 m) for the replicate test).

- The Laser RST identified a much lower quantity of cracks as compared to mapping, the manual detailed survey, or GERPHO.

Map Cracking/Scaling/Crazing

Map cracking/scaling was found to exist on almost all of the rigid test sections. The detailed visual surveys (manual and automated data logger) and GERPHO rated this distress with severity levels only. Mapping reported it as a percentage of total area, as well as severity level. ARAN rated scaling only, and did not report any scaling for these test sections. The Laser RST and PASCO did not rate map cracking/scaling.

Method	Sections (amount of map cracking in decreasing order as reported by each method)
Mapping	R7, R9, R5, R4, R3, R6, R8
Detailed Survey, Manual	R8, R6, R3, R9, R1
Detailed Survey, Automated	R7, R6, R5, R3, R1, R9, R8, R4, R2
GERPHO	R9, R8, R6, R5, R3, R2, R1
PASCO	
ARAN	
Laser RST	

In examining map cracking/scaling, the following key points were found.

- ARAN reported only scaling and although several of the test sections (R3, R6, R7) did exhibit scaling, ARAN did not report this.
- PASCO did not report map cracking/scaling.
- The Laser RST did not report map cracking/scaling.

COMPOSITE PAVEMENT TEST SECTIONS

Distress surveys were conducted on six different composite (rigid overlaid with asphaltic concrete) test sections (C1, C3, C5, C7, C8, and C9). One section was repeated immediately following the first survey (C9) and three sections were replicated on a different day (104-C3, 102-C5 and 103-C9). The identification of the replicate sections was not revealed until the data analyses were completed. Mapping and the manual detailed visual survey was done for only the initial runs, due to time constraints. The automated data logger completed replicate runs as well as initial runs. PASCO, ARAN, and the Laser RST completed all initial, repeat, and replicate runs. GERPHO filmed all initial, repeat, and replicate sections. However, the distresses were not reduced on the repeat and replicate runs because the films on the reviewing machine were found to be identical (Ref 31).

Table 23 summarizes the procedures used to report linear cracking found on composite test sections. Table 24 presents a comparison of the linear cracking reported by each method or device on each 1000-foot (305 m) composite test section. For the method of mapping, two 100-foot (30.5 m) subsections were chosen at random to be mapped. After reduction of the data, the extent of distresses in each subsection was added together and the results multiplied by five to obtain an estimate for each 1000-foot (305 m) test section.

Linear cracking (longitudinal, transverse, reflection, or any other type of cracking reported in linear feet) was found to be prevalent on all of the test sections. Mapping, detailed visual surveys (manual and automated data logger), ARAN and GERPHO reported linear cracking. PASCO reported a crack ratio, which included all cracking and patching. The Laser RST reported quantity of transverse cracks.

Table 23. Measurement of linear cracking reported on composite pavement test sections by each method or device.

Method or Device	Linear Cracking (all cracking reported in linear feet).
Mapping	Longitudinal cracking, transverse cracking reported, severity levels based on spalling, faulting, crack width. Joint reflection cracking and reflection cracking at PCC edge reported, severity levels based on spalling, random cracking, and vehicle "bump" across crack.
Detailed Visual Survey, Manual	Longitudinal and transverse cracking combined, severity level based on crack width and spalling. Joint reflection cracking reported, severity levels based on crack width, random cracking, and spalling. Edge cracking measured, severity level based on raveling.
Detailed Visual Survey, Automated Data Logger	Quantity of transverse and longitudinal cracks reported (separately) as equivalent full-width or full-length of section, severity levels based on crack width. Cracking in linear feet obtained by multiplying quantity with section width or length.
GERPHO	Longitudinal, transverse, and reflection cracking reported.
PASCO	Linear cracking measured, included in crack ratio (combines all cracking and patching).
ARAN	Longitudinal cracking measured in linear feet, severity level based on crack width.
Laser RST	No cracking measured in linear feet.

Table 24. Comparison of reported linear cracking for composite pavement sections.

SECTION	DISTRESS *	MAPPING (Linear Feet)	DETAILED VISUAL SURVEY		GERPHO (Linear Feet)	PASCO (Crack Ratio, %) (a)	ARAN (Linear Feet)	LASER RST ** (Quantity)
			Manual (Linear Feet)	Automated Data Logger (Linear Feet)				
C1	Severity	Low	Low, Moderate	Low	Low	--	0	--
	Extent	2130	38	72-120	60	0.2	0	7
C3	Severity	Low, Mod., High	Low, Mod., High	Low, Mod., High	Low, Mod.	--	Moderate	--
	Extent	3420	1245	>2612	1246	21.3	240-640	34 (a)
104 (Replicate of C3)	Severity	--	--	Low, Mod., High	--	--	Moderate	--
	Extent	--	--	>2564	--	21.4	120-320	26(a)
C8	Severity	Low	Low, Moderate	Low	Low	--	Low	--
	Extent	2180	1006	2072-2120	886	4.5	102-360	0
C5	Severity	Low, Moderate	Low, Moderate	Low, Moderate, High	Low	--	--	--
	Extent	2680	2445	>2252	1627	36.8	--	115(a)
102 (Replicate of C5)	Severity	--	--	--	--	--	Low	--
	Extent	--	--	--	--	36.9	120-320	110(a)
C7	Severity	Low, Mod., High	Low, Mod., High	Low, Moderate, High	Low	--	Low	--
	Extent	2625	2058	>4324	1185	10.6	180-480	2
C9 (Initial)	Severity	Low, Mod., High	Low, Moderate	Low, Moderate, High	Low, Mod. High	--	Moderate	--
	Extent	3450	3252	>5720	659	54.3	69-250	43(a)
C9 (Repeat)	Severity	--	--	--	--	--	Moderate	--
	Extent	--	--	--	--	54.3	400-1200	46(a)
103 (Replicate of C9)	Severity	--	--	Low, Moderate High	--	--	Low	--
	Extent	--	--	>4564	--	54.0	240-720	44(a)

* Based on the standard procedure used by each device or method.

** Includes only transverse cracks.

(a) Includes alligator cracking.

Note: 1 linear foot = 0.3048 m.

Method	Sections (amount of linear cracking in decreasing order as reported by each method)
Mapping	C9, C3, C5, C7, C8, C1
Manual Survey	C9, C5, C7, C3, C8, C1
Automated Survey	C9, C7, C3, C5, C8, C1
GERPHO	C5, C3, C7, C8, C9, C1
PASCO	C9, C5, C3, C7, C8, C1
ARAN	C9, C3, C7, C8, C5
Laser RST	C5, C9, C3, C1, C7

While examining linear cracking, the following key points were found:

- The automated data logger reported only a range of values for linear cracking.

- GERPHO's values were usually lower than those reported by mapping and the detailed visual survey systems.

- PASCO reported only a crack ratio which included all cracking and patching, and did not report distresses separately.

- ARAN reported zero cracking for Section C1 (all other methods reported some cracking for this section).

- The Laser RST did not report cracking in units of length.

CHAPTER 6. COMPARISONS AND EVALUATION

Each of the selected distress survey methods and equipment types was evaluated and compared using field testing and data analysis results. These evaluations, comparisons, and results are presented in this chapter.

FIELD EVALUATION

During the field testing, all of the devices were evaluated based on several criteria in the following categories.

- o Equipment requirements.
- o Operational characteristics.
- o Costs.
- o Robustness and durability.
- o Reliability.

Table 25 presents a comparison of these features, based on observations from the field tests performed on this project and discussions with the participants. Detailed notes on the performance of the devices during the field tests is contained in Appendix A.

Equipment Requirements

As previously noted, the distress survey methods investigated were selected due to the varying types of equipment employed. Manual measurements and visual estimates are used in the three labor-intensive methods of distress survey. In the high-speed devices, automatic non-contact systems are used for measurements. Continuous photography of the pavement surface is performed by the GERPHO and ROADRECON systems. Laser sensors are used by the RST and ROADRECON to measure rutting. The ARAN uses ultrasonic sensors for rutting.

Table 25. Summary of field evaluation of selected distress survey methods and equipment.

CATEGORY	MANUAL MAPPING	DETAILED VISUAL SURVEY-MANUAL	AUTOMATED DATA LOGGER (VISUAL SURVEY)	GERPHO	PASCO-ROADRECON	ARAN	LASER RST
<u>Equipment Requirements</u>							
(a) Field measurement equipment for surface distresses	Measuring tape	Hand-held distance measuring wheel	---	Slit 35-mm camera system	1. Pulse 35-mm camera 2. Hairline projector 3. Three laser height sensors 4. Distance measuring instrument	1. Seven ultrasonic height sensors 2. Distance measuring instrument	1. Eleven laser height sensors 2. Distance measuring instrument
(b) Field data recording equipment	Data sheets	Data sheets	Hand-held Epson HX-20 microcomputer	Slit 35-mm camera system	Slit and pulse 35-mm cameras, computer, and strip charts	Two video cameras and computer	Computer and print-outs
(c) Data transfer and office processing equipment	---	Computer	1. Computer 2. Computer cables	1. Film processor 2. Automated viewing table 3. Computer	1. Film processor 2. Film projector & measured grid pattern 3. Film projector & computer digitizer mouse 4. Computer	Computer	Computer
(d) Data storage/ retrieval equipment	Manual files	Manual files and computer	Computer	Film library & computer	Film library, manual files, and computer	Computer	Computer & manual files

Table 25. Summary of field evaluation of selected distress survey methods and equipment (continued).

CATEGORY	MANUAL MAPPING	DETAILED VISUAL SURVEY-MANUAL	AUTOMATED DATA LOGGER (VISUAL SURVEY)	GERPHO	PASCO-ROADRECON	ARAN	LASER RST
(e)Level of automation	None	Data storage	Data recording, transfer, and storage.	Data collection, interpretation, and storage.	Rut depth measurements. Data Collection, interpretation, & storage.	Data recording, transfer, & storage. Rut depth measurements.	Data recording, transfer, and storage. Rut depth measurements. Crack detection. Macrotexture measurement.
(f)Vehicle requirement	Raters transportation	Raters transportation	Raters transportation	Dedicated van	Dedicated van	Dedicated van	Dedicated van
<u>Operational Characteristics</u>							
(a)Principle of operation	Manual measurements & on-site mapping. Manual data reduction.	Manual measurements & subjective ratings. Manual data reduction.	Manual entry of subjective ratings on a hand-held microcomputer. Direct data transfer for further analysis.	Filming of pavement. Office interpretation of distresses.	Filming of pavement. Measurement of rutting with photographic method & laser measurements. Office interpretation of distress and digitizing of photographic rut measurements.	Rutting survey with ultrasonic sensors, & through-the-windshield subjective ratings of distresses recorded on computer. Video image of pavement.	Measurements using laser sensors for cracking, texture & rutting. Through-the-windshield subjective rating of distresses recorded on computer.

Table 25. Summary of field evaluation of selected distress survey methods and equipment (continued).

CATEGORY	MANUAL MAPPING	DETAILED VISUAL SURVEY-MANUAL	AUTOMATED DATA LOGGER (VISUAL SURVEY)	GERPHO	PASCO-ROADRECON	ARAN	LASER RST
(b)Distress categories	All types. See Tables 11,12,13.	Recommended procedures (PAVER, COPES). See Tables 11,12,13.	The detailed survey procedure selected for test. See Tables 11,12,13.	French procedures; also adapted distresses included in the FHWA list of Table 4. No Rutting. See Tables 11,12,13.	Japanese procedure. See Table 11,12,13.	Standard ARAN procedures. See Tables 11,12,13.	Standard IMS procedures. See Tables 11,12,13.
(c)Productivity in field	Approx 30-60 minutes for 100-foot subsection	Approx 25-35 minutes for 1000-foot section	Approx 15-25 minutes for 1000-foot section	Less than one minute for 1000-foot section	Less than one minute for 1000-foot section	Less than one minute for 1000-foot section	Less than one minute for 1000-foot section
(d)Restriction on field data collection	<u>Traffic</u> (only daytime operation on dry surface)	<u>Traffic</u> (only daytime operation on dry surface)	<u>Traffic</u> (only daytime operation on dry surface)	Night time operation only (dry condition)	Night time operation only (dry condition)	<u>Moisture</u> (for ultrasonic sensor operation). Daytime operation only (dry condition)	Daytime operation only (dry condition)
(e)Crew Size	1-2	2	1	2 (driver, operator)	2-3 (driver, operators)	3 (driver, operators)	3 (driver, rater, engineer)
(f)Operator training requirements	Technician level. One day training for an experienced rater.	College background. 1-2 weeks actual training in PAVER method.	College background. One week training.	College background. One week training.	College background. 1-2 weeks training.	College background. 2 weeks training.	Operators included in lease arrangement

Table 25. Summary of field evaluation of selected distress survey methods and equipment (continued).

CATEGORY	MANUAL MAPPING	DETAILED VISUAL SURVEY-MANUAL	AUTOMATED DATA LOGGER (VISUAL SURVEY)	GERPHO	PASCO-ROADRECON	ARAN	LASER RST
(g) Office data processing time (actual dates of receiving processed data are shown in Table 5)	10-15 min per 100-foot subsection	About 10 min per 1000-foot section for PCI calculation by PAVER method	One day to generate report for all flexible sections	Approx 1-1/2 hrs for interpretation of 1000-foot section	1 day to process & compile film. 2 days to interpret & encode distresses 1 day to transcribe & process outputs	Approx 2 days to generate reports for all sections	Reports generated in the field
(h) Raw distress data storage and retrieval requirements	Manual filing	Manual filing of coded sheets	Paper prints & cassette tapes	35-mm negative film	35-mm negative film and paper plots	Videotapes, computer floppy disks	Computer floppy disks
(i) Processed distress data storage and retrieval requirements	Manual filing	Manual filing or computerized	Computer floppy disk and hard copy output	Computer floppy disk & hard copy output	Computer tapes & hard copy output	Computer floppy disk & hard copy output	Computer floppy disk & hard copy output
(j) Quality of raw distress data	Very good	Good if done appropriately	Fair	Very good	Very good	Fair	Fair
(k) Reproducibility of measurements	Good if done appropriately	Fair	Fair	Good	Good	Fair	Fair
(l) Operating speed	Walking & stopping	Walking & stopping	Walking & stopping	40 mph	25-40 mph	30 mph	up to 50 mph

Table 25. Summary of field evaluation of selected distress survey methods and equipment (continued).

CATEGORY	MANUAL MAPPING	DETAILED VISUAL SURVEY-MANUAL	AUTOMATED DATA LOGGER (VISUAL SURVEY)	GERPHO	PASCO-ROADRECON	ARAN	LASER RST
(m)Maintenance requirement	None	None	None	Van, 35-mm camera system, hydraulic, electrical, and electronic controls	Van, 35-mm camera system, hydraulic, electrical, and electronic controls, lasers	Van, video system, hydraulic, electrical, & electronic controls, ultrasonic sensor assembly, on-board computer	Van, electrical & electronic controls, laser assembly, on-board computer
<u>Cost Parameters</u>							
(a)Equipment Cost (one pickup for each manual method)	≃ $15,000	≃ $15,000	≃ $15,500	$300,000	$500,000 approx.	up to $400,000	only on lease ($20/lane mile)
(b)Traffic control cost	Yes	Yes	Yes	None for routine use	None for routine use	None for routine use	None for routine use
(c)Field data collection cost per lane mile	$2248.00	$225.00	$113.00	$13.00	$13.00	$20.00	$45.00
(d)Data processing cost per lane mile	$ 216.00	$ 36.00	$ 12.00	$60.00	$78.00	$66.00	$24.00
<u>Robustness & Durability</u>	N/A	N/A	Satisfactory	Very good	Very good	Good	Good
<u>Reliability of Equipment</u> Failures in field tests for distresses	N/A	N/A	None	None	None	In wet conditions, ultrasonic sensors failed to work	None

The distress data is recorded manually on sheets of paper in the mapping and manual detailed survey methods. Computer cassette tape and computer disks are used by the automated data logger, ROADRECON (for laser outputs), ARAN and RST systems. The GERPHO and ROADRECON use film, and the ARAN uses VHS videotapes to record pavement image. The use of microcomputers in the instrumented survey vehicles and automated data logger facilitates data transfer, office processing, storage and retrieval.

Varying levels of automation are associated with the selected distress survey methods and equipment as shown in Table 25. The RST device features completely computerized procedures throughout the survey, beginning from field data collection to the in-field report generation. The GERPHO and PASCO ROADRECON-70 are automated photography devices. All of the instrumented survey vehicles used a dedicated van. For the three labor-intensive methods, any type of vehicle can be used for transporting raters and field measurement equipment to and from the test sites.

Operational Characteristics

On-site mapping in the daytime and manual data reduction is used in the manual mapping method. This makes it the most time-consuming procedure. Mapping provides an image of the pavement surface as seen by human eyes, and is subject to variations due to subjectivity in identifying distress types and the artistic skill of the mapper. The GERPHO and PASCO ROADRECON-70 take continuous photographs of the pavement surface at night in artificial light. These photographs are very repeatable and capture all visible characteristics of the pavement surface.

The ARAN device records a video image, which was not as sharp as the 35-mm film image. Special video equipment was needed to view these images. The videotapes are not currently used for distress interpretation. The 35-mm films and video image of the pavement surface were made in black and white. The lack of color may have caused loss of clarity so that several features of the pavement distresses, that would easily be seen and recorded by manual mapping, would be missed. For example, a small patch or pothole both show as lighter areas in a negative film and, therefore, it is difficult to distinguish between the two, but in mapping these are clearly identifiable. It is also possible that under certain lighting conditions, visual observations can miss distresses such as cracking, that are not missed by the photographic methods using a fixed lighting scheme.

For rutting, the three high-speed devices (ROADRECON, ARAN, and RST) use objective measurements. ROADRECON uses a photographic technique. ARAN uses ultrasonic height sensors. ARAN uses subjective ratings for all other distresses. RST uses laser height sensors. RST also uses laser sensors for cracks. The laser sensors, however, may not detect the cracks filled up with sand or dirt. The RST device uses subjective ratings for longitudinal and alligator cracks. Distress categories identified and rated by these methods and equipment are listed in Tables 11, 12, and 13.

The total time spent at each test section and the time during actual testing were used as measures of field productivity for the methods. This includes time required for setup of the method or equipment, positioning for the beginning of the section, testing, and returning to the transport condition. The four instrumented survey vehicles were set up prior to tests on the first section. Table 25 shows their actual time on the 1000-foot (305 m) sections, which was generally less than 1/2 minute. For rut depth measurements, the ROADRECON system needed time to adjust the camera and run the section a second time. The manual mapping was the slowest method. Traffic was the primary operating restriction for all manual methods. Moisture caused several interruptions in the functioning of ultrasonic sensors used in the ARAN device during field testing.

The operating crew size and operator training requirements influence the operating cost of any method or equipment. The use of the automated data logger for visual surveys was the most economical among all manual methods. The GERPHO and PASCO ROADRECON devices require small crew sizes and involve less complex training than required for ARAN and RST. Table 5 gives a summary of time taken by each method or equipment to furnish the processed data. The RST device was the fastest according to this criterion, because it did not require any office data processing. However, interpretation of the outputs from the ARAN and RST was complicated and required some experience to fully understand the outputs. The raw and processed data storage and retrieval requirements are summarized in Table 25.

The quality of raw distress data is an important criterion for this evaluation. The maps and photographs provide a permanent record of the pavement surface. Mapping, GERPHO, and PASCO ROADRECON are rated very good because the images of the pavement surface can be referred to in the future and reinterpreted as desired. The other methods were rated fair due to the subjective nature of the distress interpretations. Their end product is a number in a particular distress category which cannot be reinterpreted in the future.

Operating speed affects field productivity. Manual mapping was the slowest method because the rater walks along the section and makes intermittent stops to measure and map distresses. Detailed visual surveys (both manual and automated data logger) are also performed at walking speed. Stopping was also required to record the information, or observe a distress in more detail. The four automated devices are operated at standard highway or posted speeds. The high-speed devices require regular maintenance of the dedicated vans and other parts of the system. Devices featuring multi-function measurement systems, like the ROADRECON system, ARAN, and RST, obviously require more maintenance than GERPHO.

Costs

Table 25 provides a comparison of costs associated with equipment, traffic control, field data collection, and office data processing. These cost summaries are taken from detailed cost estimates included in Appendix D. The instrumented survey vehicles appear cost-effective on a long-term basis. In addition, the multi-functional devices could be even more cost-effective if their additional capabilities (other than the distress surveys) were used on a regular basis.

Robustness and Durability of Equipment

Based on limited field experience and interviews with the participants, the instrumented survey vehicles were judged to have acceptable durability. The particular GERPHO unit tested was 7 years old and had traveled 160,000 miles (257,496 km). It had been used for about 38,000 miles (61,000 km) of photographic distress surveys in France, according to the participating team leader. The ROADRECON unit used in this study was built in 1983, and had surveyed 190,139 miles (306,000 km), according to the operating team. The ARAN unit used in this study was brand new and experienced some problems. On the first day of testing, the calibration of the distance measuring instrument (DMI) was checked and found defective. An engineer who was flown in from Canada fixed the problem in one day. The RST device used in this study had been operated in the United States since mid-1986.

Reliability of Equipment

The field tests were monitored continuously by the research team. The only problem occurred with the ARAN. The ultrasonic sensors of the ARAN failed to function during one day of field testing. This was attributed to moisture and wet conditions of the pavement surface. The operators did not detect this while they were in the field. This required a return trip to these sections to obtain the measurements with the ultrasonic sensors.

The processing of ROADRECON films and digitization were done in Japan. The Japanese participants lost several weeks due to a problem caused by the company who shipped the film to Japan. One of the film containers was also opened by the shipping company. Fortunately, only the edge of the film was exposed. The quality of the pictures on this roll were not adversely affected.

COMPARISON OF DISTRESS DATA

A comprehensive analysis of distress data collected and reported by the selected methods and equipment was presented in Chapter 5. Three labor intensive manual methods were used to compare the outputs of the four types of instrumented survey vehicles. Mapping also provided a direct comparison against the photographs made by the GERPHO and PASCO ROADRECON-70. Major findings of the analysis are summarized below.

GERPHO

GERPHO provided two types of data reports; GERPHO's standard output and a detailed output based on customary U.S. units using the distresses listed in Table 4. Several categories of cracking were identified in the reports for flexible sections. As with all condition survey procedures that rely on interpretation by a human rater, minor differences were found between what the study team regarded as the actual distresses present on the sections and those identified by the GERPHO technician. Patching on flexible pavements was difficult to interpret from the films. It was practically impossible to identify lane-shoulder drop-off and joint faulting. However, the study staff could identify distresses from the films and attribute the differences in rating to the subjective opinion of the rater. The GERPHO equipment does not feature any instrument to identify or measure rutting.

GERPHO's standard output reports the number of transverse cracks on rigid pavements. This information can be used to calculate average crack spacing on continuously reinforced concrete pavement (CRCP). In general, the number of transverse cracks per section were less than the amount reported from the manual visual surveys. This indicates that some hairline cracks (typical of CRCP) were not identified by the rater interpreting the films.

PASCO

PASCO's data reports were based on standard Japanese outputs. All types of cracking and patching were combined into a composite index which is not directly comparable with the data reported by other devices. Although PASCO used their standard method of distress interpretation, distress from their photographs can easily be interpreted with most common distress survey formats used in the United States. The quality of the PASCO film was judged to be slightly better than that of the GERPHO. Rut depth measurements made with the ROADRECON-75 are based on a unique photographic technique that provides a transverse profile of the section. Comparison of independent manual measurements with a 10-foot (3 meter) straightedge corresponded well with PASCO's rut depth measurements with the ROADRECON-75.

ARAN

Distress data (except for rutting) was collected subjectively while traveling at 30 mph (48 kmph). Rutting was measured objectively by ultrasonic sensors. All data interpretation was done in the field.

On flexible pavement sections, the ARAN did not identify all the cracking on the sections reported by the manual surveys. Potholes were identified, but patching was not. The cracking and potholes reported from the repeat runs did not correspond well with those from the initial survey.

Rut depth data based on the ultrasonic measurements, is reported for both wheelpaths at 0.02 mile (32 m) intervals. These rut depths were generally less than those measured with a 10-foot (3 m) straightedge.

On rigid pavement sections, transverse crack spacing was reported as a range in which 0 to 20 feet (0 to 6 m) was the first interval. This information is inadequate for CRCP evaluations. In addition, although several of the test sections exhibited scaling, the ARAN did not identify it.

Laser RST

Lasers detected cracks (generally transverse, diagonal, and meandering cracks), and subjective ratings are entered for alligator cracking, longitudinal cracks, and other distresses.

On flexible pavement sections, the Laser RST identified only one (out of seven) sections that had alligator cracking. The extent of longitudinal cracking was not reported. Only a range of crack widths is reported, i.e. less than or greater than 0.5 inches (13 mm). The Laser RST reported zero cracks for Section 300 which had some transverse cracking. Potholes and patching were not reported by the Laser RST.

During the initial survey of some CRCP sections, no transverse cracks were detected. Adjustments were made to the crack detection threshold settings and the sections were rerun. Some transverse cracks were detected during these runs but the number of cracks were considerably underestimated when compared to the number of transverse cracks reported by mapping, manual survey methods, and GERPHO.

RANKING OF THE SELECTED DEVICES

Comparative evaluation of the manual methods and all four instrumented survey vehicles (GERPHO, PASCO ROADRECON, ARAN and Laser RST) was made from the following perspectives:

- Availability of a permanent record of the pavement surface.
- Evaluation and comparison based on the analysis of surface distress and rutting data.
- Instrumentation evaluation and comparison of the performance based on hands-on experience and field tests.
- Cost-effectiveness.

Table 26 presents the criteria used for comparison and ranking of the selected methods.

Table 26. A summary of comparison and ranking of the selected methods.

CRITERIA	Manual Mapping	GERPHO	PASCO ROAD RECON	ARAN	Laser RST	DETAILED VISUAL SURVEY	
						Manual Recording	Automated Data Logger
1. Permanent Record of Pavement Surface							
Reliability	3	2	2	1	5	5	5
Field Productivity	5	1	1	1	5	5	5
Usefulness	3	1	1	4	5	5	5
2. Field Data Collection, Processing, Interpretation, and Summary							
Level of Automation	5	2	2	2	1	4	3
Accuracy	2	2	2	4	4	3	3
Quality of Rut Depth Data	1	5	1	2	2	3	3
Repeatability	2	1	1	3	3	3	3
Ease of processing	2	3	4	2	2	2	3
Ease of interpretation of outputs	1	1	2	3	3	1	1
3. Operating Restrictions							
Environmental Effects	2	2	2	3	2	2	2
Traffic Interference	5	1	1	1	1	5	5
Operating Speed	5	1	1	1	1	5	4
4. Equipment Durability and Robustness	1	1	1	2	2	1	1
5. Cost Effectiveness	5	1	2	2	1	4	3

Rankings: 1 = Very Good 2 = Good 3 = Fair 4 = Poor 5 = Very Poor

Permanent Record of Pavement Surface

An image of pavement surface serves as a useful permanent record of pavement surface features. It facilitates fast and easy checking of the data without having to make a return visit to the field. Side-by-side comparisons of the images of a pavement surface, obtained during distress surveys performed at different times, allow investigation of the development of distresses. Features initially thought insignificant may be discovered to be a significant indication of the development of distress. This is especially useful for long-term pavement performance research studies. The other aspect of images of the pavement surface is the voluminous amount of film or videotape which must be stored. Locating particular points of interest on a pavement section can also be time consuming. Methods of using laser videodisks to store the visual information promise better storage and access than the methods investigated in this study. At the time of this study, none of the devices investigated used the laser disk system although several of the representatives claimed to be working on it.

The detailed visual surveys and Laser RST do not create images of the pavement surface. Their output are numbers indicating the severity and extent of the observed distresses and characteristics of the pavement surface. Future investigations of the historical development of distress on a pavement section have no recourse but to rely on these ratings and measurements. Thus, from a research perspective, these methods were rated very poor in terms of a permanent record of the pavement surface.

Reliability. The manual mapping method, similar to that used at the AASHO Road Test (Ref 1), produces detailed maps prepared with labor intensive measurement procedures and drawings on specially prepared mapping sheets. For reliability, this method was rated fair because of the subjective nature of identifying distress types and severity, and inherent variation due to human factors. The GERPHO and PASCO ROADRECON-70 develop images from 35-mm film. Because this film, in the undeveloped state, is subject to loss due to improper handling and exposure, these devices were rated good (rather than very good) in terms of reliability.

The ARAN video image can be viewed while it is being made and any problems can be detected immediately. Due to this feature, its reliability was rated very good.

Field Productivity. Manual mapping is the most time consuming and laborious method and was ranked very poor in field productivity. PASCO, GERPHO, and ARAN all use objective procedures at relatively high speeds to produce an image of the pavement surface and were rated very good.

Usefulness. PASCO's and GERPHO's films are very sharp and were judged adequate for interpretation of distresses. The photographs from the PASCO device were slightly clearer than those from the GERPHO although both were very acceptable. The usefulness of both of these devices' photographs of the pavement surface were rated very good. The video images produced by the ARAN were judged poor and not adequate for interpretation of all types of pavement distress. Its usefulness was ranked poor.

The usefulness of the manually prepared maps was judged fair due to the subjective nature of the distress interpretations and the possibility that pavement features are not recorded which appear insignificant, but which may become important at a later date.

Field Data Collection, Processing, Interpretation, and Summary

Criteria in this category include level of automation, accuracy of surface distress data, quality of rut depth data, repeatability, ease of processing, and ease of interpretation of outputs.

Level of Automation. Automation is a primary consideration for cost-effective distress survey procedures. Mapping is not an automated method and was rated very poor. In detailed manual visual survey methods, field data collection, processing, and interpretation is done manually. However, the data can be input into the computer and used to generate reports. Therefore, they were ranked poor. The automated data logger was given a fair rating due to the reduction in time and cost to transfer the field data to an office computer for processing. The GERPHO, PASCO, and ARAN instrumented vehicles were rated good because further processing of the field data is required in the office. The automation of the Laser RST was rated very good because all of the information collected with this device is processed in the field by the on-board computer.

Accuracy of Surface Distress Data. Accuracy of the distress survey data was defined as how close the reported distress data corresponded to the distresses actually on the test sections. This definition includes the influence of the subjective opinion of the rater interpreting the distress. The "truth" was taken as the ratings from the three manual methods when they were all in agreement. Where conflicts in the data from the manual methods existed, return trips to those sites were made by the members of the study team to resolve the conflicts. This was not an easy task, and many lively discussions were held among the study staff at the sites concerning the interpretation of the distresses present.

No one method was found to be totally correct for all sections. Among the manual methods, differences were found with what the study team concluded was the truth after several visits to the sites. The manual mapping method yielded results that more closely approximated what the truth was judged to be. It was given a good rating. The information from the GERPHO was also in close agreement with the observed distresses (very good). The form of distresses reported from the PASCO ROADRECON-70 were somewhat difficult to directly compare, but they was also judged to be of good accuracy. The accuracy of the detailed visual surveys was judged to be fair even though they were used, in-part, to help define the actual conditions. As might be expected, the accuracy of the surface distress information collected through the windshield of the ARAN and Laser RST were not as accurate as the other methods, and were judged poor.

Quality of Rut Depth Measurements. Quality of the rut depth measurements was based on the accuracy of the measurement and the amount of detail provided for the transverse profile. Accuracy of the rut depth measurements was determined by comparison against transverse rut profiles manually measured with a 10-foot (3 m) straight edge. The amount of detail was judged good if both a transverse profile and maximum rut depth were produced.

Since the GERPHO does not measure rut depth, it was rated very poor in this category. The manual mapping method was rated very good because the 10-foot (3 m) straightedge was considered as a part of this technique. Since the PASCO ROADRECON-75 rut depth measurements corresponded very well with the straightedge measurements and detailed transverse profiles were produced, it was rated very good.

The maximum rut depth measurements made with the ARAN and Laser RST were less than those measured with the straightedge. However, due to differences in measurement intervals the accuracy of these rut depths could not be directly evaluated against the straightedge measurements. Although the ARAN measured a transverse profile using sensors spaced at one-foot (0.3 m) intervals, only the maximum rut depth was reported. The Laser RST gave the average and standard deviation of the depth measurements made with each laser, which gives some information on the transverse profile shape, but did not give profiles for each measurement made. Since the Laser RST made approximately 3,000 measurements on each section, if transverse profiles were produced the amount of information would be overwhelming. Based on these considerations the ARAN and Laser RST quality of rut depth measurements were rated good.

The accuracy and detail provided with the detailed visual surveys were rated fair. Some discrepancies were found in both the extent and severity of rutting reported by these methods. These survey techniques are not designed to produce information on the transverse profile of the pavement.

Repeatability. This criterion is related to the differences between the reported distresses from repeat measurements and return visits to the test sites by the study staff. The PASCO measurements showed excellent agreement between its initial and repeat measurements and was therefore ranked very good. The distresses from the GERPHO photographs were not interpreted for the repeat measurements. Since the repeat photographs of the test sections made with the GERPHO were judged to be of equal quality by the study staff as the initial photographs, the repeatability of this device was also rated very good. The rut depth measurements made with the ARAN and Laser RST had good repeatability, however, significant differences were found in the ratings of the other surface distresses. Since rut depth is only one distress category, these two devices were rated fair in overall repeatability.

Detailed survey methods showed discrepancies between raters. Repeat measurements with the same rating team yielded fair repeatability. The repeatability of the manual mapping technique was rated good.

Ease of Processing. The ease of processing the raw data is rated based on the required background and training for the technician(s) and the complexity involved in the processing. The lower the requirements for operator training and the less complex the process, the higher the rating. These ratings are relative to each other and should not be considered as an absolute measure, i.e. a method rated as poor was judged to require more operator training and be more complex than one with a fair rating. Mapping was rated good even though it is laborious and time consuming. It is a straightforward process requiring technicians to summarize, from the prepared maps, the distresses which have been interpreted in the field. The ease of processing the GERPHO photographs was rated fair because a technician trained to interpret the photographs with keyboard skills is required.

The PASCO techniques were rated poor overall in the ease of processing due to the complexity of the procedures and the following requirements for their technicians: that they operate a digitizing computer for rut depth measurements, that they be trained for interpretation of the distresses from the photographs, and that they have keyboard skills for entry of the interpreted data into a computer. Because the technicians who process the raw data from the ARAN and Laser RST are not required to interpret the distresses, the ease of processing was rated good. The ease of processing the data from the detailed condition survey was also rated good. Although keyboard entry skills are required to enter the data into the computer, the technicians processing the data are not required to interpret distresses. The automated data logger was rated as fair because it was slightly more complex due to the need to have the technician transfer the field data to the office computer prior to final processing.

Ease of Interpretation of Outputs. The ease of interpreting the reports or final output from each method was rated according to how easy it was to understand the outputs. All of the manual methods and GERPHO were ranked very good because the reports were given in terms of severity and extent of distresses in clearly distinguishable categories. The reports from the PASCO ROADRECON device were only rated as good primarily because they were produced on an output format printed in Japanese and because cracking, patching, and potholes were lumped into one category. It should be noted that a user agency should be able to reformat reports into their desired format, using the ROADRECON equipment. The ARAN and Laser RST devices were ranked fair because interpretation of their output was complex and not straightforward. The manuals and written procedures which accompanied their reports were also found to be complex and required more effort to understand than the other methods.

Operating Restrictions

There are three criteria in this category which are summarized in Table 26 and are discussed below.

Environmental Effects. There is no method that can be used during all weather conditions, or at all times of the day and night. All methods are rated good except ARAN which was rated fair due to the problems caused by the rain with the ultrasonic sensors during field tests.

Traffic Interference. Traffic interference during distress surveys affects the quality and quantity of distress data. None of the four instrumented survey vehicles interrupt traffic, pose hazards, or require lane closure or other traffic controls for routine use. These were ranked very good. All manual methods are subject to potential conflicts with traffic due to the presence of the rating team on the side of the road or in the traffic lane to perform measurements. Therefore, the manual mapping and visual condition survey methods were ranked very poor.

Operating Speed. The operating speed is related to productivity and cost-effectiveness of the complete system. Labor intensive methods (mapping and manually-recorded detail survey) were ranked very poor, followed by the automated data loggers, which was somewhat faster and was rated poor in comparison to the instrumented survey vehicles. The instrumented survey vehicles were rated very good on this ranking scale.

Equipment Durability and Robustness

These are important considerations for long-term performance of a device. The manual mapping and detailed visual distress survey methods use equipment that is not subject to breakdowns or that require little maintenance and were, therefore, rated as having very good equipment durability and robustness. The GERPHO and PASCO ROADRECON devices, also rated very good, have a long history of use in their respective countries and performed without problems during the field tests. The ARAN device tested in this study had two malfunctions during the testing period that were corrected without great delay. Although it was a new machine which had not had all of the "bugs" worked out, it was assigned a good reliability rating in comparison to the other methods. The Laser RST was also given a good rating in equipment reliability and robustness because the instrumentation involved with the use of lasers and interfaces with the on-board computers could be subject to more potential problems than the equipment rated as very good.

Cost Effectiveness

Cost-effectiveness involves costs associated with several parameters: field productivity, operating crew size, office data processing time, manpower requirements, and usefulness of data. Based on the study presented in Appendix D, GERPHO and Laser RST were ranked very good, followed by the other two instrumented survey vehicles. The automated data logger is rated fair. The manual recording of distress survey methods and mapping are ranked poor and very poor, respectively.

OVERALL RANKING

The overall ranking of the methods and techniques investigated in this study for use in conducting research studies of pavement performance were developed by the study staff based on our relative weighting of the importance of the ratings presented in the previous section. In developing these ratings we gave the greatest weight to those methods which produce permanent records of the pavement surface distresses, which allow multiple interpretations over time by many researchers. Based on these considerations the following overall rankings were assigned. Methods with equal ranking are listed alphabetically.

Methods	Rank
GERPHO	1 (very good)
PASCO ROADRECON	1 (very good)
Manual methods (Mapping, Manual recording detailed survey, Automated data logger)	3 (fair)
ARAN	4 (poor)
Laser RST	4 (poor)

It must be remembered that these rankings are based on conducting distress surveys for pavement research purposes. Readers interested in use of these methods for other purposes should consider the individual ratings and evaluate them against their proposed use.

The use of the instrumented vehicles for pavement distress research studies is further discussed in the following sections.

<u>35-mm Continuous Photographic Systems</u>

The GERPHO and PASCO-ROADRECON systems were ranked as the top choices for conducting distress surveys for pavement research purposes. Both systems are mounted on dedicated vans and provide a permanent film record of the pavement surface after each survey. Both require two operators for field tests and these people need not be highly skilled in roadway evaluation and distress recognition techniques. The method of data collection from films insures uniformity because the same equipment is used for viewing the film and the interpretation is based on the same criteria. Comparisons of surveys done at two different times can be made easily at the office interpretation station and will allow the detailed knowledge of progressive deterioration. Moreover, it is convenient to "go back" to a pavement section just by viewing the film.

If it is desired to put into operation one of these two devices on a regular basis, at present GERPHO is the recommended choice. In this study, GERPHO has shown the adaptability of its methods to local requirements in the United States. The GERPHO team was able to develop and process their films in Austin immediately after the field tests, set up their interpretation table and office analysis station, and analyze and generate reports for several test sections within 3 to 4 days. Furthermore, they developed software and reports using customary U.S. units and typical distress categories used in the United States. In its present configuration, GERPHO is not capable of measuring rut depth. However, the GERPHO team indicates the intention to assemble a GERPHO in the United States, corresponding to specific requirements that will use a U.S. van and will be able to, with additional equipment on-board or in-tow, measure rutting and faulting (Ref 9).

On the other hand, the ROADRECON series of PASCO offers several other capabilities besides collecting surface distress data. The ROADRECON systems use 35-mm continuous strip film in combination with one or more of the following options: 1) use of a hairline projector and 35-mm pulse camera to take photos of cross profile for measuring rut depths, 2) use of laser sensors for measuring rut depths and faulting, and measuring longitudinal roughness. In the future, PASCO will also offer a laser disk based pavement condition data/image retrieval system (Ref 8). The roughness data reported in this study as recorded by PASCO could not be validated in the field by comparison with proven data. For regular routine use, it is desirable to use a separate device to measure longitudinal roughness. The following findings reflect only surface distress data collection, rut depth, and faulting measurements.

- PASCO indicates its capability to generate reports based on typical distress categories used in the United States as shown in Appendix D. There is no information on how much effort and time is needed to adapt the Japanese system to these requirements.

- Rut depth measurement by PASCO are more accurate than the measurements reported by the Laser RST and ARAN devices.

- Joint faulting measurements by PASCO using lasers may be a viable technique. The accuracy of this method could not be checked independently in this study.

ARAN and RST

In their present status and configuration, the ARAN and the Laser RST are not recommended as distress survey equipment suitable for use in pavement research studies for the following reasons:

- The ARAN's video logging capability is not adequate to reduce distress data because of insufficient resolution and lack of adequate pattern recognition. If this capability is perfected to produce adequate distress data, it could be preferred over the conventional 35-mm continuous strip film methods. Such is not the case now.

- Although the use of lasers is a promising approach, the Laser RST needs several improvements as mentioned by the manufacturer (Ref 13). Future improvements needed include objective characterization of crack types by lasers and a video imaging system.

- The accuracy and reliability of the visually-rated distresses at 30 to 50 mph (48 to 80 kmph) is obviously not as good as the data collected by a rater who can see the film of the pavement section at his own pace and repeatedly if necessary.

- The operators of the ARAN and RST devices require training in distress identification and data collection procedures. For the 35-mm photographic methods, the operators require less skill in distress identification.

CHAPTER 7. SUMMARY AND RECOMMENDATIONS

A summary of the findings from the investigation of a select number of distress survey methods, which offer increasing levels of automation, is presented in this chapter. The evaluation of the devices for use in research studies of pavement performance are summarized here by each device. A detailed discussion of the evaluation and ratings of each device was presented in Chapter 6. Recommendations are included in this chapter for the use of the distress survey methods and equipment in network and project level pavement evaluation. This chapter closes with recommendations on an expanded study of several devices for implementation in the Long Term Pavement Performance study for the Strategic Highway Research Program.

SUMMARY

Based on a review of information on pavement distress surveys, the following seven distress survey methods and devices were selected for study and evaluation:

- Manual mapping.
- Detailed visual survey with manual recording.
- Detailed visual survey using automated field data logger.
- GERPHO survey vehicle.
- PASCO ROADRECON survey vehicle.
- ARAN survey vehicle.
- Laser RST survey vehicle.

Field tests with these methods and equipment were conducted over a three month period from July to September 1986. Distress surveys were conducted on 25 test sections comprised of flexible, rigid, and composite pavements exhibiting a wide range of distresses. Repeat surveys were conducted with some of the devices on the same day. Replicate surveys were performed on a subset of the test sections on a different day.

Each method and device was evaluated and rated by the study team against the following criteria: 1) permanent record of pavement surface; 2) field data collection, processing, and interpretation; 3) operating restrictions; 4) instrumentation precision and reliability; 5) equipment durability and robustness; and 6) cost-effectiveness. An overall ranking of each method and device was developed based on a relative consideration of these criteria. Major findings for each method and device are summarized below.

Manual Mapping

Detailed mapping of pavement surface conditions as carried out at the AASHO Road Test provides a permanent record of pavement surface distresses. Distress data are then reduced from maps and summarized in the office. Among all the manual methods, maps provide an accurate representation of the distresses present on a pavement if properly prepared in the field. However, this method is laborious and time consuming in the field as well as during the office data reduction. The reliability is not considered as good as that of a photo record due to the subjective visual element involved in interpreting and drawing the distresses. Mapping is not very cost-effective and was considered fair in the overall ranking as a standard condition survey method for pavement research studies.

Detail Visual Survey-Manual Recording

Detailed visual surveys, using manually recorded data, are the most commonly used condition survey method in the United States. Training is required of the field raters to achieve uniform and consistent interpretation and ratings of distresses. Many pavement distress identification manuals have been developed which are used in the field by the raters, but these generally do not use uniform definitions for distress types, severity, and extent. The resulting distress data typically lacks adequate reliability and repeatability due to the inherent subjectivity of human ratings. Depending on the level of detail of the required information, collection and processing of this information can be a time consuming task. The data is not considered as accurate as that reduced from maps or photographs by a technician in the office. The end result of this type of method is a report of the extent and severity of various distress types which does not identify locations of distress occurrences and which cannot be reinterpreted in the future. The manual recording of the field ratings on data sheets for subsequent transcription into a computer data base resulted in a poor rating for cost-effectiveness. Overall this technique was given a fair ranking as a standard condition survey method for pavement research studies.

Detail Visual Survey - Automated Data Logging

The use of an automated data logger for field data collection is a logical first step for automating distress survey methods. The data is entered on a hand-held microcomputer by the rater instead of using manual data forms. The field productivity is slightly better than that of using manually coded forms. However, significant efficiency is achieved in transferring the data to the central office or directly into a computerized data base. The method also offers the capability of transferring data directly from the field over telephone lines. The office data reduction, analysis, and report generation using an automated data logging system is very easy and fast. This technique also suffers from the same subjective elements as that of the visual condition surveys. The cost-effectiveness was rated fair. Its overall rating for use in pavement performance research studies was rated fair as was the manual recording technique. If manual pavement distress surveys are considered, either for pavement research studies or routine condition survey for management purposes, use of automated data loggers are recommended over manual recording techniques.

GERPHO

The GERPHO survey vehicle takes 35-mm continuous strip photographs of the pavement surface at night. It has been in extensive use in France for over a decade. The night operation and adaptability of the speed to suit traffic conditions make it convenient and productive. The operators need not be skilled in roadway evaluation techniques. The processed black-and-white film is analyzed in the office using a special viewing table for distress identification and data collection. Data can be entered directly into a microcomputer for storage and report generation. It is a simple system to operate in the field and also in the office data analysis. The pavement distresses may be interpreted from the film using most of the current standard definitions and rating methods. The film serves as a permanent record of the distresses on the pavement surface and may be reinterpreted in the future to study distress propagation. The GERPHO was rated very good in cost-effectiveness and very good overall for use in pavement research studies.

PASCO-ROADRECON

The PASCO-ROADRECON-70 system takes 35-mm continuous strip photographs of the pavement at night at varying speeds. The distresses are interpreted from the black-and-white film using a 35-mm strip film projector and a rectangular overlay grid. Although the PASCO practice is to record the distress information on written data sheets for transcription into a computer, there is no reason why the interpreter cannot also enter distress information directly into a computer. The quality of the photographs from the ROADRECON-70 were judged to be slightly better than those from the GERPHO. The ROADRECON-75 system uses a unique photographic method to measure the transverse profile of a pavement to determine rut depths. The transverse profile is input into a computer using a "mouse" digitizer. These rut measurements were found to correspond well with those measured with a 10-foot (3 m) straightedge. Detailed plots of the cross section profile were produced showing how the rut depths were determined. The reports submitted by PASCO were printed in Japanese formats which were then adapted into English. The instrumented survey vehicle from PASCO contains other equipment for measurement of joint faulting, rut depth, and longitudinal roughness which were not evaluated on this project. This equipment has been successfully used in Japan for over 12 years. The cost-effectiveness was rated good and the overall rating for use in pavement performance research studies was rated very good.

ARAN

The ARAN features automation of rut depth measurements, recording of windshield distress survey information, and video images taken of the pavement surface in black and white with a panoramic view of the right-of-way in color. At present, the video image of the pavement surface is not used for interpretation of pavement distresses. The study staff's opinion of the resolution quality of the video picture of the pavement surface was that it was not adequate for interpretation of all pavement distresses. The rut depth measurements using ultrasonic sensors were found to be less than those measured with a 10-foot (3 m) straightedge, however, due to differences in measurement intervals, the accuracy of these rut depths could not be directly evaluated against the straightedge measurements. The distress ratings made through the windshield while traveling along the section did not compare well with those found with the detailed visual surveys. The ARAN was rated good in cost effectiveness due to the high data collection productivity in the field tests. The ARAN was given an overall rating of poor for use in pavement research studies. It is more suited to routine condition surveys at a network level to develop priority rankings of pavement sections for pavement management and rehabilitation purposes.

Laser RST

The Laser RST features the use of laser distance measuring technology for measuring rut depths and surface macrotexture and for detecting transverse cracking. An on-board computer is used to record visual distress information. This was the only instrumented survey vehicle tested in this study which did not create some type of image of the pavement surface. The crack detection system did not work well on detecting the small hairline transverse cracks in continuously reinforced concrete pavements. It could also not detect longitudinal cracks, diagonal cracks, or cracks filled with sand or dirt. These type of cracks and other surface distresses were estimated by raters in the van by windshield survey and entered into the on-board computer. The rut depths reported from this device were less than those measured by the 10-foot (3

m) straightedge, however a direct comparison was not possible since the Laser RST measured the transverse profile every 10 cm and reported the average maximum rut depth at 30-meter intervals. The straightedge measurements were made at 50-foot (15 m) intervals. All distress information reports were generated using the on-board computer while still in the field. Due to this feature, it was rated very cost-effective. The outputs produced by the device were judged by the study team to be complex and difficult to interpret and understand. An overall rating of poor was given to the Laser RST for use in pavement research studies. It is more suited to routine condition surveys at a network level to develop priority rankings of pavement sections for pavement management and rehabilitation purposes.

RECOMMENDATIONS

Recommendations are provided here on the use of the distress survey methods and equipment investigated for network and project level pavement evaluation for pavement management purposes, and for an expanded study of several devices specifically for implementation in the Long Term Pavement Performance study for the Strategic Highway Research program.

Distress Surveys for Pavement Management

Distress surveys for pavement management purposes are conducted at two levels, network and project level evaluations. Network level evaluations are conducted over a road or highway network to determine its condition and establish priorities for improvements to the sections competing for limited funding. Project level evaluations are conducted to provide information with which to design specific improvements or 4R measures (resurfacing, rehabilitation, restoration, and reconstruction). There is a wide variation in the type and application of distress surveys for network and project level evaluations. A great deal depends on the magnitude of the network, the type of pavement structures (thin or thick, rigid or flexible), type of agency (state DOT or local city government) and available funding. In the next two paragraphs, general features of network and project level distress surveys are discussed.

Network level surveys do not require the same degree of detail as needed for project level design. Only summary information is generally needed on critical distresses such as cracking, potholes, patching, and rutting for network level surveys. Sometimes roughness is added to these distress ratings to form a composite rating index, generally varying from 0 to 100. Since networks can have extensive lengths, the speed of the field survey is an important consideration. Network level surveys can be used to determine sections requiring more extensive project level evaluations.

Project level surveys for design purposes require adequate detail to allow decisions to be made on appropriate types of improvements and work programs for the improvements. These surveys are often associated with nondestructive deflection tests and limited coring and materials sampling to determine the pavement structure characteristics. Since the length of projects are generally not long, the emphasis of the distress survey is on accuracy and detail. Speed is not the primary consideration.

The PASCO and GERPHO photographic survey vehicles can be used for both network level and project level distress surveys. They are capable of covering extensive networks in a relatively short time. Either summary or detailed distress information can be interpreted from the photographs as desired. Photographs taken over time can yield useful information on the development of distress to update distress prediction models. The additional rut depth and roughness measurement equipment contained on the PASCO vehicle give it additional utility for both network and project level surveys. While these vehicles provide the basis for good quality distress information, the costs associated with film development, office interpretation, and film storage may offset their advantages for some agencies. Although a permanent visual record of a pavement surface has the advantages discussed in this report, these records are not necessary for a good network level pavement management system.

The other two distress survey vehicles investigated in this study, the ARAN and Laser RST, lend themselves to network level distress surveys. They both supplement windshield type distress ratings with measurements of rutting and roughness. They are capable of covering networks in a relatively short time. Since the distress information and pavement surface measurements are recorded on on-board microcomputers, the turn around time on completion and assembly of the processed information is also relatively short.

Both the ARAN and the Laser RST provide information which are not traditionally needed or used in pavement management data bases. The ARAN provides information on longitudinal grade, cross fall, and directional heading, which can be useful but is not required for most network level pavement management systems. The Laser RST provides the user with measures of the macrotexture of the pavement surface. Some interesting interpretations of this data is possible, but unless this information is correlated with skid resistance, it is of very limited use.

The video cameras on the ARAN provides additional information that may be useful to an agency. The through-the-windshield view of the road environment provides information useful for inventory purposes. While, in our opinion, the image of the pavement surface from the shuttered video camera was not adequate for interpretation of all distresses, it does provide a record of major distresses, such as potholes, that can be useful to the engineer in the office as a check on questionable ratings, or to investigate a section of road that is of interest, prior to making a field trip.

Both the ARAN and Laser RST performed well in our field tests. We recommend that they be considered for use by an agency performing a network level pavement evaluation. It is recommended that an agency contemplating the use or purchase of these survey vehicles first inspect the information contained in this report regarding the features measured by each vehicle and the format of the data reports, to decide which vehicle is appropriate for the anticipated use. Since further developments to the vehicles are being performed, it is also suggested that the equipment representatives be contacted for new information. It may be possible to arrange for demonstrations of the new units. We do not recommend that these survey vehicles be considered for project level distress surveys for design purposes.

Manual surveys are the traditional approach to distress surveys. It is recommended that an agency performing manual surveys use an automated data logger to record the distress survey information in the field and for transfer to an office computer. It is also recommended that some form of printed output, such as a paper tape, be generated at the time the information is recorded to serve as a backup in case data recording errors are encountered. Manual mapping is not recommended for network or project level distress surveys for pavement management purposes.

Distress Survey Study for SHRP-LTPP

The GERPHO and PASCO devices rank very good as high-speed distress survey devices for permanent research records. It is recommended that one of these two devices be strongly considered for use in the SHRP/LTPP and other pavement research studies.

It is also recommended that one or both of the devices using the 35-mm photography, GERPHO or PASCO, be further evaluated on selected test sections in various environmental regions of the United States along with a detailed survey procedure. The detailed survey procedure should be made and repeated on an automated data logger for comparison.

The configuration and details of both GERPHO and PASCO are changing with technology. It is important to establish a desired configuration and a desired data handling methodology for pilot LTPP studies. These details must be the subject of negotiations with the two manufacturers and compared in the pilot study. The benefits of purchase or leasing must also be evaluated.

Aside from GERPHO and PASCO, at present no other high-speed devices for distress surveys are recommended for potential use in SHRP. The alternate is a well-developed automated visual method with good dimensional and locational records.

The results of this pilot test plan will be useful for the research community as well as highway agencies. It would allow investigation of the adaptability of the selected device to local requirements and provide additional information on maintenance requirements, durability, and robustness of the equipment after it has been subjected to long distance travel.

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APPENDIX A. DESCRIPTION OF DISTRESS SURVEY METHODS AND EQUIPMENT

This appendix provides a detailed description, operating procedure, and field notes for each of the selected distress survey methods and devices.

MAPPING

The method of manual mapping used for the distress survey test sections was similar to the method used for the AASHO Road Tests (Ref 1). Manual mapping, although labor-intensive, provided a permanent record of the pavement surface. With this method, raters manually recorded on a map the type and location of all distresses present on the pavement surface.

Equipment Description

To aid in mapping distresses, a 100-foot (30.5 m) tape measure, marked at twenty 5-foot (1.5 m) intervals was laid along the side of each 100-foot (30.5 m) subsection. The 5-foot (1.5 m) intervals corresponded to the 5-foot (1.5 m) intervals on the distress mapping form. A tape was also used to measure the extent of the distresses and a 10-foot (3.05 m) straightedge was used to measure rut depths. The only other equipment needed was a supply of distress mapping forms and a clipboard to use as a writing surface.

Operating Procedure

Upon arriving at the test section, the width of the pavement was measured and recorded along with the remainder of the header information. The test section was mapped in 20-foot (6.1 m) intervals. All distresses were identified, measured, and recorded on the distress mapping form. The severity level (low, medium, high) was also recorded. Distress rating standards were based on the "Highway Pavement Distress Identification Manual" (Ref 2). The distresses which could not be drawn on the form, i.e., raveling, bleeding, etc were noted in the space provided for comments on the mapping form. Sample completed field distress maps are shown in Appendix B.

Data Processing and Interpretation

In the office, the distress data was reduced using the 1 foot-by-1 foot (0.3 m-by-0.3 m) grid printed on the map so the extent of the distresses could easily be measured from the maps. The data was recorded for each 20-foot (6.1 m) subsection and compiled for the two 100-foot (30.5 m) subsections that were mapped. The total was then multiplied by five to obtain an estimate for the 1000-foot (305 m) test section. Reduced data from a flexible and a rigid test section are presented in Figures 10 and 11, respectively.

DETAILED VISUAL SURVEY (PAVER)

PAVER (Ref 3) is a pavement evaluation system developed by the U.S. Army Construction Engineering Research Laboratory. The primary input used in PAVER is pavement condition ratings, in the form of a pavement condition index or PCI. The PCI, obtained through a field condition survey, is a relative measure or ranking of a pavement.

Equipment Description

The equipment used to carry out PAVER field inspections included a hand odometer to measure slab size and distress lengths, a 4-foot (1.2 m) straightedge and scale to measure rut depths, clipboards for a writing surface, and a supply of field forms. The "APWA PAVER Pavement Condition Index Field Manual" (Ref 4) was used to identify distresses and determine the severity level.

Operating Procedure

The distress survey was conducted by walking each unit and measuring the severity and extent of each distress. Survey sections were divided into sample units according to the PAVER recommendations. Asphalt

DATA FROM DISTRESS MAPS (FLEXIBLE AND COMPOSITE PAVEMENTS)

Section No: 44 Test Date: 4Aug86 Time to Complete Test: 53 Min.

DISTRESS TYPES		SubSection 3 0-20'	20-40'	40-60'	60-80'	80-100'	SubSection 6 0-20'	20-40'	40-60'	60-80'	80-100'	Total for 200'	Estimated Total for 1000'
Alligator Cracking	*S	L	L	L			L	L	L	L	L	L	L
	*E(S.F.)	10	40	18			15	34	38	56	51	262	1310
Bleeding	*S						M	M	M	M	M	M	M
	*E(S.F.)						200	200	200	200	200	1000	5000
Block Cracking	*S												
	*E(S.F.)												
Edge Cracking/ deterioration	S	L	L	M	L	L	L					L	L
	E(L.F.)	5	14	8	2	4	3					36	180
Lane/Shoulder Dropoff	*S												
	E(L.F.)												
Longitudinal Cracking	*S	L	L	L,M	L	L		L	L	L	L	L,M	L,M
	*E(L.F.)	1	5	12	26	37		11	1	7	29	129	645
Reflection Cracking	*S												
	*E(%)												
Potholes	*S												
	*E(No.)												
Patching	*S										P	P	P
	*E(S.F.)										46	46	230
Pumping	*S												
	*E(No.)												
Raveling	*S							L				L	L
	*E(S.F.)							11				11	55
Joint Reflection	*S												
	*E(L.F.)												
Rutting	*S	M	M	M	M	M	L,H	L,H	L,H	L,H	L,H	L,M,H	L,M,H
	*E(S.F.)	120	120	120	120	120	120	120	120	120	120	1200	6000
Slippage Cracking	*Yes/No												
	*E(S.F.)												
Transverse Cracking	*S			L			L	L		L		L	L
	*E(L.F.)			1			2	3		22		28	140

S - Severity (L - Low, M - Medium, H - High)
E - Extent
(S.F.) - Square foot
(No.) - Number
(L.F.) - Linear foot

(%) - Percent of Surface Area

*Based on Highway Pavement Distress Identification Manual (FHWA, 1986)

Figure 10. Form used to reduce data from flexible and composite pavement sections.

DATA FROM DISTRESS MAPS (RIGID PAVEMENTS)

Section No: R6 Test Date: 21Aug86 Time to Complete Test: 44 Min.

DISTRESS TYPES		SubSection 4 0-20'	20-40'	40-60'	60-80'	80-100'	SubSection 5 0-20'	20-40'	40-60'	60-80'	80-100'	Total for 200'	Estimated Total for 1000'
Construction Joint Distress	*S												
	*E(No.)												
Corner Break	*S												
	*E(No.)												
Depression	*S												
	*E(No.)												
Joint Seal Damage	*S												
	*E(L.F.)												
Lane/Shoulder Dropoff	*S												
	E(L.F.)												
Lane/Shoulder Jt. Separation	*S												
	E(L.F)												
Longitudinal Cracking	*S												
	*E(L.F.)												
Patching	*S					G	G					G	G
	*E(No.)					1	1					2	10
	*E(S.F.)					30	96					126	630
Popouts	Yes/No				Y	Y					Y	Y	Y
	*E(No.)				3	2					1	6	30
Pumping	*S												
	*E(No.)												
Punchouts	*S												
	*E(No.)												
Scaling, Crazing, Map Cracking	*S	L	L	L	L	L	L	L	L	L	L	L	L
	*E(%)	100	100	100	100	90	60	100	100	100	100	95	95
Spalling of Jts and Cracks	*S												
	*E(No.)												
Transverse Cracks (CRCP)	*S	L	L	L	L	L	L			L		L	L
	*E(No.)	5	2	3	4	6	2			3		25	125
	*S	M	M	M	M	M	M	M	M	M	M	M	M
	*E(No.)	6	6	4	6	3	2	6	5	7	7	52	260
	*S												
	*E(No.)												

S - Severity (L - Low, M - Medium, H - High)
E - Extent
(S.F.) - Square foot
(No.) - Number
(L.F.) - Linear foot

(%) - Percent of surface area

*Based on Highway Pavement Distress Identification Manual (FHWA, 1986)

Figure 11. Form used to reduce data from rigid pavement sections.

sections were divided into sample units approximately 12 feet (3.7 m) wide by 200 feet (61 m) long, or 2400 square feet (223 square meters). Five sample units made up each asphalt test section of 1000 feet (305 m). Composite pavements (rigid overlaid with asphaltic concrete) were treated as asphalt pavement for the survey. Jointed concrete pavement sections were divided into samples units of approximately 20 slabs. Since PAVER does not handle continuously reinforced concrete pavement at this time, those sections which were CRCP were rated using "COPES", which will be discussed in a following section.

A two-person crew was used in the field. One person measured distress density while the other person recorded the distresses. Interaction between the two crew members in "calling" distresses was an important check to help reduce subjectivity. Flexible pavement distresses were measured in square feet, linear feet, or quantity, as listed below.

Flexible Distresses Measured in Square Feet	Flexible Distresses Measured in Linear Feet	Flexible Distresses Measured as a Quantity
Alligator Cracking	Bumps & Sags	Potholes
Bleeding	Edge Cracking	
Block Cracking	Joint Reflection Cracking	
Corrugation	Lane/Shoulder Drop off	
Depression	Longitudinal & Transverse Cracking	
Patching		
Polished Aggregate		
Railroad Crossing		
Rutting		
Shoving		
Slippage Cracking		
Swell		
Weathering/Raveling		

All JRCP distresses were counted on a slab-by-slab basis except for joint seal damage, which was rated for the entire sample unit. Each flexible and JRCP distress was rated for severity, as well as extent. Sample raw field data of a flexible and a JRCP section can be found in Appendix B.

Data Processing and Interpretation

Pavement condition indices (PCIs) were calculated for the pavement test sections after the field survey. The PCI can range from 0 to 100 in value. Lower values are indicative of a poor pavement condition while higher PCI values indicate pavements in good condition. The following steps were used to determine PCI values.

1. Use deduct curves (Ref 3) for each distress type and severity to determine deduct values. To use the deduct curves, distress density must first be computed. In general, the density is the amount of distress (extent) divided by the sample unit area (for asphalt pavement) or the number of slabs in the sample unit (for jointed concrete pavement). A deduct value is a number from 0 to 100 with a 0 indicating the distress has no impact on pavement condition and 100 indicating an extremely serious distress which causes the pavement to fail.

2. Sum all individual deduct values to determine a total deduct value (TDV).

3. Use correction curves to determine the corrected deduct value (CDV) from the TDV. The correction curves allow for the proper summation of individual distress deduct values when more than one distress type was observed.

4. Compute the PCI using the relation PCI=100-CDV.

5. Average PCIs of sample units to obtain PCI of entire section.

After the PCI's were calculated, pavement condition ratings for each section were determined using the following scale (Ref 3).

PCI	Rating
86 - 100	Excellent
71 - 85	Very Good
56 - 70	Good
41 - 55	Fair
26 - 40	Poor
11 - 25	Very Poor
0 - 10	Failed

DETAILED VISUAL SURVEY (COPES)

The overall objective of COPES is to provide a system to periodically collect and evaluate data from in-service concrete pavements (Ref 5). The system consists of three major components: data collection, storage and retrieval, and evaluation. Data collection includes historical data (traffic, climate, etc) as well as distress data. For the storage and retrieval component a data base management system, Scientific Information Retrieval (SIR), is used. Evaluation includes such items as design evaluation, rehabilitation needs, and construction and materials evaluation. For this project, only the distress data was collected.

Equipment Description

The equipment used for the COPES surveys included a tape measure, data sheets, and a clipboard to use as a writing surface. The COPES manual (Ref 5) was also used as a reference to rate distresses.

Operating Procedure

A two-person crew was utilized in the field. The crew first drove over the test section at 55 mph (88 kmph) or at the legal speed. The number at each severity level of depressions and swells was recorded.

Each person gave an estimate of PSR (Present Serviceability Rating) and their estimates were averaged and this number was then recorded. The crew then walked the section and recorded the quantity of full-width (or equivalent) transverse cracks. Longitudinal cracks in 6-foot (1.8 m) increments were also recorded. The following distresses were also identified.

- Blowups.
- Reactive Aggregate Distress.
- Pumping.
- Scaling/Map Cracking/Crazing.
- Longitudinal Joint Spalling.
- Localized Distress.
- Edge Punchouts.
- Construction Joint Deterioration.
- "D" Cracking.
- Lane/Shoulder Separation.
- Patching.
- Patch Adjacent Slab Deterioration.

The COPES data sheets were used to record the distresses. However, longitudinal and transverse cracks were recorded on data sheets that were developed for this project. Sample data sheets are presented in Appendix B. Finally, the crew slowly drove over the section and recorded any additional distresses (not recorded on the previous run). For this project, the distress data taken in the field was not processed. However, COPES data sheets are prepared for direct input into a computer to be further processed.

AUTOMATED DATA LOGGER

The automated data logging system used for the distress survey tests (Figure 12) was based on a pavement evaluation and management system developed for the Rhode Island Department of Transportation by ARE Inc (Ref 6). The system allowed data to be input directly into a field data

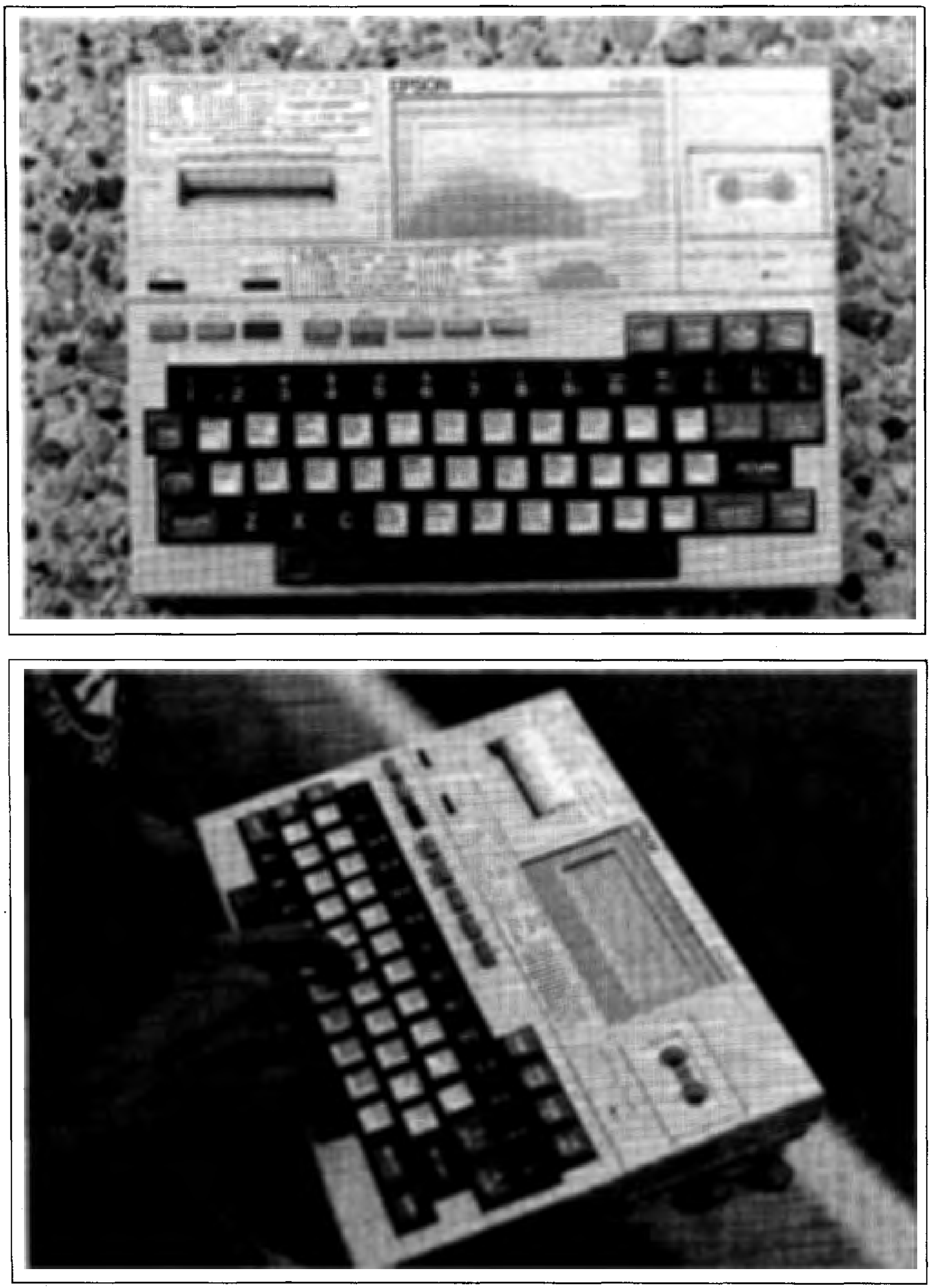

Figure 12. Two views of the EPSON HX-20 portable computer used for automatic data logging.

recorder, and to be transferred to a microcomputer for further processing in the office.

Equipment Description

An EPSON HX-20 portable computer was used in the field to record section identification information as well as distresses. The EPSON keyboard, used for automatic data logging was shown in Chapter 2 (Figure 4). A 10-foot (3.05 m) straightedge was also utilized in the field to make an estimate of rut depth. The severity level of rutting was based on this estimated depth. No other equipment was used in the field.

Operating Procedure

For each pavement test section, the rater first drove (or quickly walked) through the section in order to identify the distresses that were present, to rate the more prominent pavement characteristics and distresses (such as the number of potholes), and to check the section for homogeneity (to see if the amount or type of cracking changed significantly or if the pavement structure of geometry changed significantly, etc). The rater then slowly walked the section to record the severity and extent of distresses and the pavement identification information. The distresses rated for flexible and composite (rigid overlaid with asphaltic concrete) pavements are listed in Table 27. A sample of the hard copy produced in the field is shown in Appendix B.

Because the survey system was developed for flexible pavement systems, the data logger had to be adapted to handle different distresses. This was accomplished by a cross reference table that listed the rigid distresses that corresponded to the flexible codes (and appeared on the hard copy of the raw data produced in the field). The severity level and extent of rigid distresses were defined by the Portland Cement Concrete Evaluation System, "COPES" (Ref 5). The distresses rated for rigid pavements are listed in Table 28.

Table 27. Flexible and composite distresses rated by the automated data logger (the code appearing on the hard copy of the raw data produced in the field is noted in parenthesis following each entry).

Distress	Severity Level	Extent
Alligator Cracking (ALL) and Block Cracking (BLK)	Low (L), Moderate (M), Severe (S)	Percentage of Total Area 1-10%(1), 11-20%(2), 21-50%(3), 51-80%(4), 81-100%(5)
Longitudinal Cracking (LNG)	Low (L), Moderate (M), Severe (S)	Total number of full length cracks, several short cracks are added together
Transverse Cracking (TRN)	Low (L), Moderate (M), Severe (S)	Equivalent number of full width cracks: 1-5(1), 6-10(2), 11-15(3), 16-20(4) over 20(5)
Rutting (RUT) and Edge Deterioration (EDGE)	Low (L), Moderate (M), Severe (S)	Localized (1), Throughout (2)
Bleeding (BLD) and Raveling (RVL)	----	Localized (1), Throughout (2)
Potholes/Patches (PTH) & Utility Cuts (UTL)	Good (G), Poor (P)	Quantity: 1-2(1), 3-5(2), 6-10(3), 11-15(4), 16-20(5), 21-30(6), 31-40(7), over 40(8)
Long Longitudinal Cuts & Patches (LLP) and Intersections (INTS)	Only poor cuts & patches & intersections are rated	Number of occurrences is noted
Pavement Drainage (DRN)	Good (1), Poor (2)	----
Shoulders	Good (G), Poor (P)	Paved(1), Gravel(2), Earth(3), Curb(4)

Table 28. Rigid distresses rated by the automated data logger (the code appearing on the hard copy of the raw data produced in the field is noted in parenthesis following each entry).

Distress	Severity Level	Extent
Longitudinal Cracking (LNG)	Low (L), Moderate (M), Severe (S)	Quantity: 1-5(1), 6-10(2), 11-15(3), 16-20(4), over 20 (5)
Transverse Cracking (TRN)	Low (L), Moderate (M), Severe (S)	Quantity: 1-10(1), 11-20(2), 21-30(3), 31-40(4), over 40 (5)
Blowups (RUT), Durability "D" Cracking (BLK), Edge Punchouts (EDGE), and Construction Joint Deterioration (ALL)	Low (L), Moderate (M), Severe (S)	Quantity or Number of areas: 1-2(1), 3-5(2), 6-10(3), 11-15(4), 16-20(5), 21-30(6) 31-40(7), over 40 (8)
Pumping/Bleeding (BLD), Scaling/Map Cracking/ Crazing (RVL), and Lane/ Shoulder Separation (LLP)	Low (1), Moderate (2), Severe (0)	-----
Longitudinal Joint Faulting (DRN) and Patch Adjacent Slab Deterioration (INT)	-----	Number of areas: 1-2(1), 3-5(2), 6-10(3), 11-15(4), 16-20(5), 21-30(6), 31-40(7), over 40 (8)
Patch Deterioration (PTH), Depressions (UTL), and Localized Distress (SHL)	Low (G), Moderate (G), Severe (P)	Quantity of low or severe: 1-5(1), 6-10(2), 11-20(3), 21-40(4), over 40(5); Quantity of moderate: 1-5(6), 6-10(7), 11-20(8), 21-40(9), over 40(0)

Data Processing and Interpretation

The automated data logger saved distress data on a computer-encoded microcassette. Hard copies of the data were produced in the field. Thus, the rater had two forms in which data had been recorded. Once in the office, the collected distress data was down loaded from the portable computer to a microcomputer. This was accomplished by using hardwired connections between computers and the RS-232C Communications Protocol. Once a data file had been set up on the micro computer, the data could be further processed. The distress data collected for the flexible and composite pavement test sections were further processed, using a Pavement Management System developed by ARE Inc (Figure 13).

PASCO ROADRECON

Figure 14 illustrates the PASCO Road Survey Vehicle (called PASCO ROADRECON equipment in this study) used in the field tests. This unit was built in 1983 and has traveled over 190,000 miles (306,000 km), according to the Japanese team who also mentioned that five units are in service in Japan with an annual survey of about 6200 miles (10,000 km) per unit. Four different ROADRECON instruments were installed in that unit. These were: ROADRECON-70 (35-mm continuous strip film photography), ROADRECON-75 (hairline projector and 35-mm photography for rut depth), ROADRECON-77 (longitudinal roughness using a fifth tracking wheel), and ROADRECON-85B (laser sensors for faulting and rut depth). Table 29 summarizes the historical background of the PASCO's Road Surface (PRS) Condition Survey System. Principles of operations and equipment description (based on Ref 8) for ROADRECON-70, ROADRECON-75, and ROADRECON-85B, pertinent to the objectives of this study, are presented below.

Principles of Operation

The ROADRECON-70 is a high-speed, continuous road surface photographic recorder using a 35-mm slit camera. The film speed, the vehicle speed, and the intensity of illumination are synchronized so that a proper response of the film is always maintained. The camera lens (14.5-

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*** CONDITION SURVEY REPORT ***

SECTION NUMBER	STREET NAME	SEQ NO.	SURF TYPE	LENGTH (FT)	TRANSVERSE	LONGITUDNL	ALLIGATOR	RUTTING	BLEEDING	EDGE DETR	RAVELING	BLOCK CRCK	PATCHING		UTIL CUTS		SCORE
					LMS	LMS	LMS	LMS		LMS		LMS	G	P	G	P	
44	Decker Lake EB	1	F	1000	2	2	1	2	2	2		1					54
41	FM 3177 SB	1	F	1000		2	1	2	1	2	2						77
56	Greg Manor NB	1	F	1000		1	5	2		2				6			30
4	Decker Lake EB	1	F	1000		1	41	2	2	2			2				57
19	US 183 NB	1	F	1000				2	1								90
55	FM 969 WB	1	F	1000				2	2	21	2			1			62
7	US 183 SB	1	F	1000	1		1	2		1							89
C5	IH 10 WB	1	C	1000	51	11	51				2			4			51
C1	IH 10 WB	1	C	1000	2												99
F1	SH 71 EB	1	F	1000	1	1	1										97
F4	SH 71 WB	1	F	1000	1		2	1						1			90
100	SH 71 WB	1	F	1000	2		2	2	1				1				85
104	US 90 EB	1	C	1000	543	2	1	1		2	2			1			51
103	US 90 EB	1	C	1000	345	121	51			1	1			8			30
C3	US 90 EB	1	C	1000	553	2	1	2		2	2	1		2			41
C9	US 90 EB	1	C	1000	555	131	5			1	1	1		8			30
C8	IH 10 WB	1	C	1000	2	2	1	1					1				93
C7	SH 60 SB	1	C	1000	521	22	2	2	2		1		1	2			52
300	Bee Caves Rd WB	1	F	1000	2			1	1	1						1	79
41	FM 3177 SB	2	F	1000				2	2	1	2						75
44	Decker Lk Rd EB	2	F	1000			1	21	2	2			1	1			60
7	US 183 SB	2	F	1000	1		1	1					2				95

	--- TRANSVERSE ---	- ALLIGATOR -	---PATCH/UTILITY CUTS---		---RUTTING/BLEEDING--- EDGE DETERIORATION RAVELING
L - LOW			G - GOOD	P - POOR	
M - MODERATE	1 - 1-5	1 - <10%			
S - SEVERE	2 - 6-10	2 - 11-20%	1 - 1-2	5 - 16-20	
	3 - 11-15	3 - 21-50%	2 - 3-5	6 - 21-30	
	4 - 16-20	4 - 51-80%	3 - 6-10	7 - 31-40	1 - LOCAL
	5 - >20	5 - 81-100%	4 - 11-15	8 - >40	2 - THROUGHOUT

Figure 13. ARE Inc condition survey report produced from distress data recorded by automatic data logger.

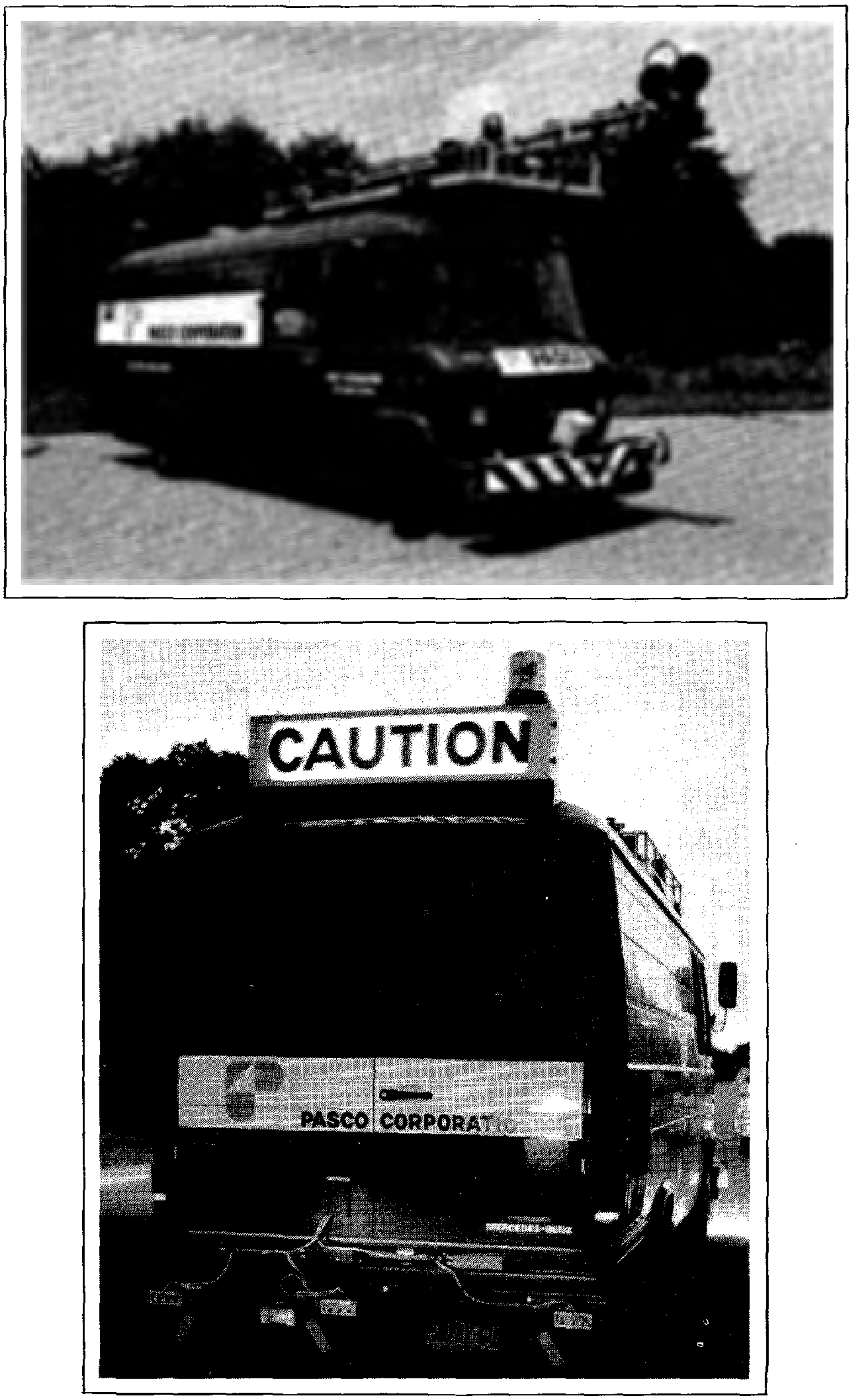


Figure 14. Side view (top) and rear view (bottom) of PASCO ROADRECON systems.

Table 29. A summary of PASCO's ROADRECON equipment development history.

1965	Design of Automatic Continuous Road Surface Photographic Recorder on Vehicle (ROADRECON-70) was begun.
1970	First ROADRECON-70 was implemented.
1975	First Automatic Rut Depth Photographic Recorder (ROADRECON-75) was implemented.
1977	First longitudinal roughness survey equipment (ROADRECON-77) was implemented.
1980	Design of Laser Sensor Longitudinal Roughness Survey Equipment (ROADRECON-85) was begun.
1982	Design of Automated Film Analyzing System for Rutting Measurement was begun.
1983	Automated Film/Data Analyzing System with Digitizing Tablet was developed.
1984	Laser Sensor Longitudinal Roughness Survey Equipment (ROADRECON-85) was developed.
1986	Patent of New Laser Camera Logging System was filed. Development of Laser Disk Based Pavement Condition Data/Image Retrieval System was begun.

mm) is held at 2.9 m vertically from the road surface. Therefore, photographic reduction can be expressed by 14.5 mm/2.9 m or 1/200 as illustrated in Figure 15.

The ROADRECON-75 photographs an optical bar projected on the road surface as illustrated in Figure 16. If the projector angle is set at $26^{o}33'$ and a pulse camera is set perpendicular to the road surface, then the rut depth (RD) can be obtained using the following equation.

$$RD = (H/f) \times [(d_1 + d_2)/\text{Cot}\theta] \quad (1)$$

where:

$d_1 + d_2$ = rd = rut depth as observed in the photograph

$\text{Cot}\theta = \text{Cot}\ (26^{o}33') = 2.0$, other terms as defined in Figure 16(b).

The photographing scale is 15 mm/3 m or 1/200. The system automatically photographs at regular intervals by synchronizing the camera shutter and the flashing of the hairline projector with the vehicle speed.

The ROADRECON-85B uses three laser sensors, mounted on the rear bumper, to measure longitudinal roughness, joint faulting, and rutting of the road surface at 0 to 50 mph (0 to 80 kmph). The principle of operation is illustrated in Figure 17.

Equipment Description

Various configurations of the ROADRECON survey vehicle can be designed according to PASCO (Ref 8). A combination of ROADRECON-70, ROADRECON-75, ROADRECON-77, and ROADRECON-85B was used in the field tests. The survey vehicle shown in Figure 14 is comprised of:

- A full-size diesel van (Mercedes Benz) fitted with a rotating yellow light on the roof.
- Engine-driven generator and power controlling panel.
- Instruments used for the four ROADRECON series.

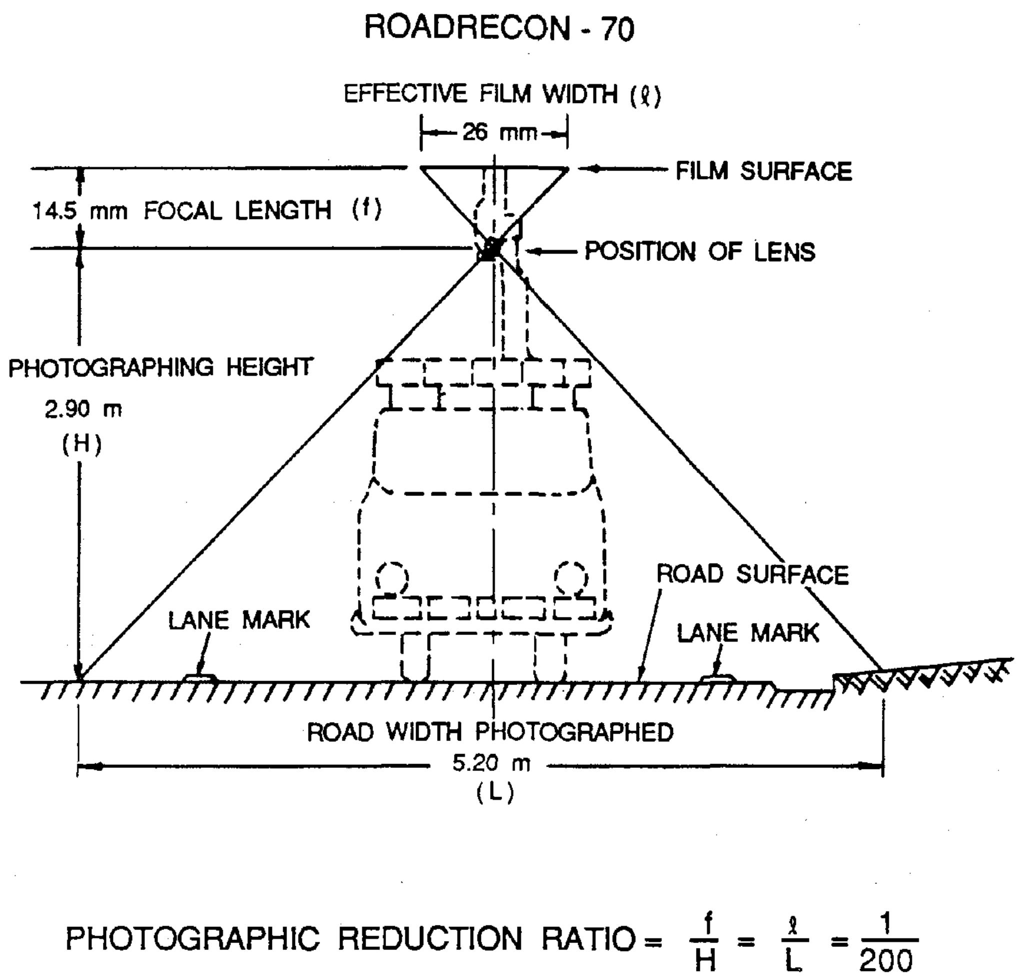
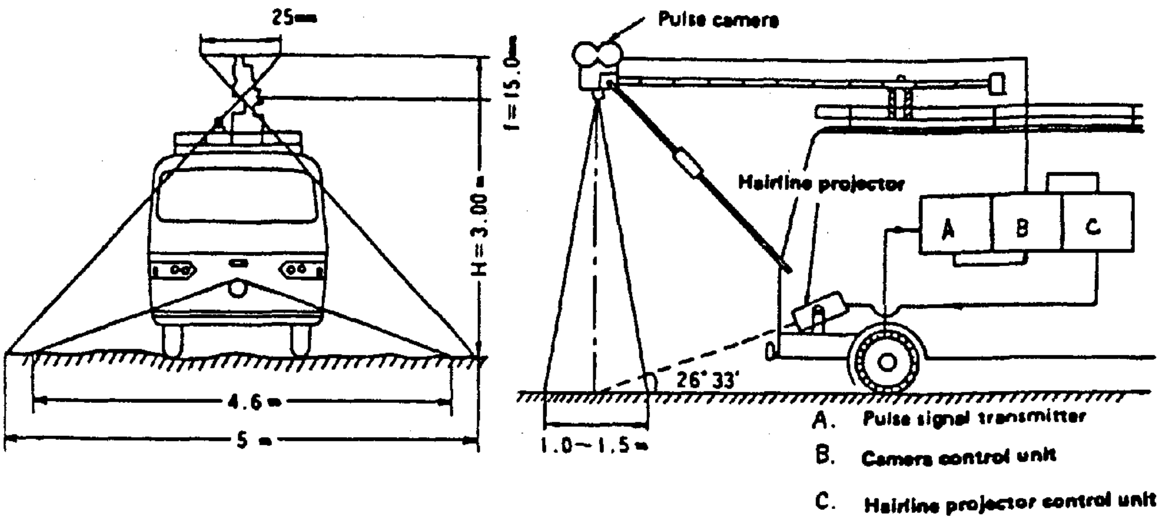
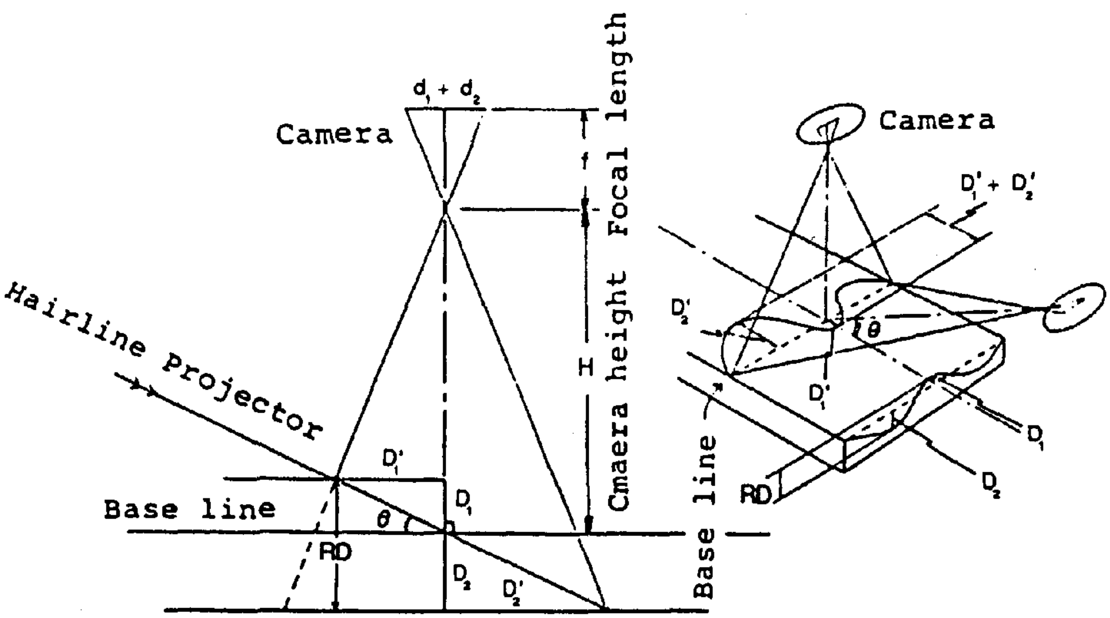


Figure 15. Photographing scale of PASCO'S ROADRECON-70.



(a) ROADRECON - 75 System mounted in vehicle.



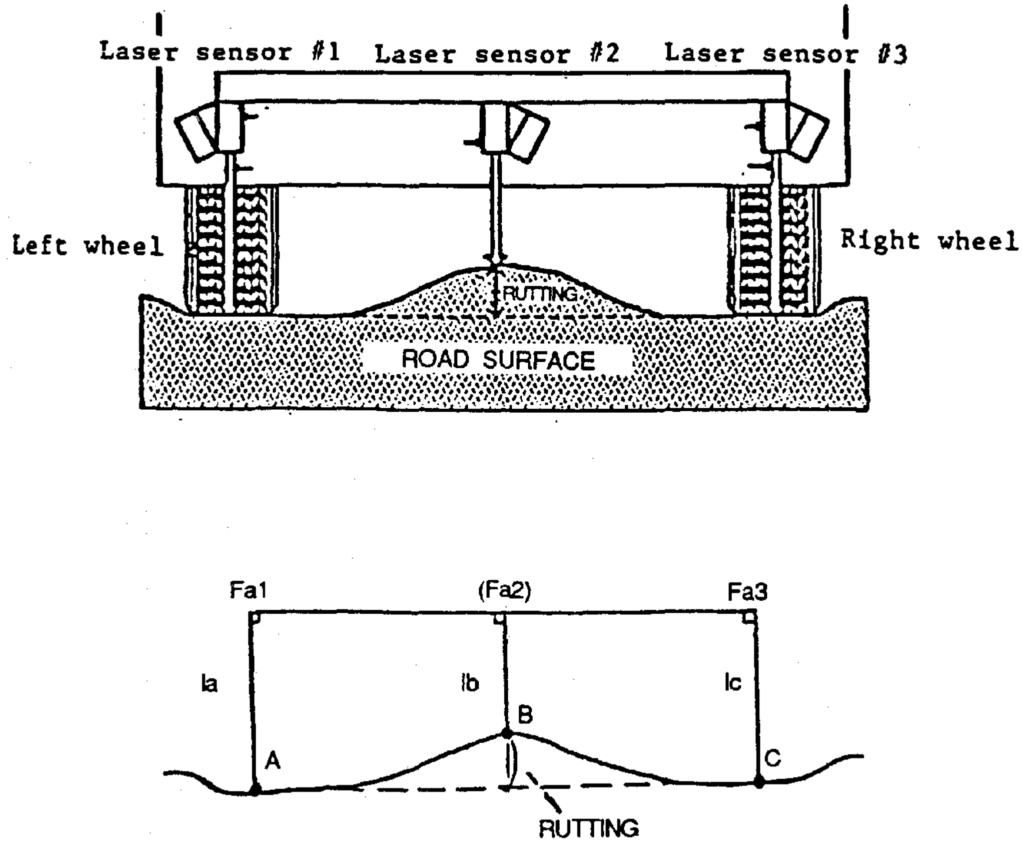
RD : Rut depth

$d_1 + d_2$: Rut depth as observed in photo (rd)

θ : Projection angle of hairline projector

(b) Geometric relations between Optical Bar and Camera.

Figure 16. Principle of the ROADRECON-75.



Longitudinal profile
Right wheel path: Fa3 = la
Left wheel path: Fa1 = lc

Rutting: $RD = \frac{la + lc}{2} - lb$

Figure 17. Principle of ROADRECON-85B.

ROADRECON-70. The camera is a 14.5-mm Angenieux lens with aperture of F3.5, a 26-mm long slit with a continuously variable width between 0.1 and 1.0 mm, and perforated 35-mm film (double X, ASA250) in a roll of 1000 feet (305 m) which will film about 37 miles (60 km) of 17 feet (15.2 m) width of road surface. The illumination source is comprised of ten halogen lamps at a projection angle varying between 25° and 35°. The camera is fixed on a supporting device to maintain its standard height of 9.5 feet (2.9 m). The supporting device uses a sliding type beam mounted on a roof rack. The control panel has monitoring indicators as well as remote starting functions, thumb wheels for data insertion, safety lights, speed monitor, and end-of-film indicator. The camera is pulse driven and controlled by an encoder from the transmission of the vehicle. Markers are used to specify special features (structures, mile post, etc) and the film is marked every 10 meters.

ROADRECON-75. The camera is changed to a pulse camera (focal length of the lens = 15-mm) using the same mounting as used with the ROADRECON-70. The hairline projector with strobe tube is mounted to project a dark line directly under the pulse camera at an angle of 26°33'. A separate control panel is provided for the ROADRECON-75. The control panel has indicators which allow the operator to monitor pulse rate, synchronized signals, speed, special insertions and end of film. The camera shutter and hairline projector are synchronized by pulse signals according to the distance covered by the vehicle. The pulses are variable between 0.1 and 99.9 m. A 400-foot roll of 35-mm black-and-white film can film 75 miles (120 km) at 66-foot (20 m) intervals.

ROADRECON 85-B. The following are various components of the ROADRECON-85B and their functions.

Component	Function
Three laser sensors	To measure distance to the ground
Encoder	To detect odometer signal (distance)
System Controller	To process measured data
Operation Panel	Start and stop system to input road mileage data
Cassette Tape	To store survey data
Pen Recorder	To record survey data (i.e. longitudinal profile, rutting, and survey speeds)

ROADRECON-77. This equipment is used to survey and record longitudinal roughness. The following components are mounted on the vehicle: tracking wheel in the outside wheelpath, a differential transformer to measure displacements of the tracking wheel, an accelerometer to measure the vibration of the vehicle, an operating circuit to subtract the amount of vibration of the vehicle from the displacement of the tracking wheel, a pen recorder, and cassette magnetic tape which records the longitudinal profile data. The recording paper feed is synchronized with distance.

Operating Procedure

Two operators are used with the PASCO road survey vehicle. The ROADRECON-70 system can be operated in day or night; the night time is preferred to obtain uniformity of photo resolution under a fixed exposure condition. The operating speed can vary between 0 and 50 mph (0 and 80 kmph). Generally, it is operated at the normal driving speed. It is possible to photograph up to 125 miles (200 km) per night. Water and snow on the pavement are operating restrictions for any type of visual or photographic distress survey method.

The ROADRECON-75 system is operated only during the night at normal driving speeds. The system uses the same vehicle, power source, camera support, and control system as used for ROADRECON-70. Therefore, for rut depth the vehicle has to make another pass after the first pass of the

ROADRECON-70. Rut depth data was collected only on flexible pavement sections in Austin at intervals of 50 feet (15 m).

The ROADRECON-85B is operated simultaneously with the ROADRECON-70 at normal driving speeds. It can be operated in the daytime independently. The operator who handles the control panel also takes care of the cassette and chart recorder.

The ROADRECON-77, used to measure longitudinal roughness of the outside wheelpath, is operated independently. The operator's panel controls raising and lowering of the tracking wheel. Speed is visible to the operator. It can be operated day or night at a speed between 0 to 25 mph (0 to 40 kmph).

Data Processing and Interpretation

The films obtained from ROADRECON-70 and -75 are developed and edited in the photo laboratory. The automatic film processor used by PASCO can develop five 1000-foot (305 m) rolls a day which is equivalent to a 190 lane mile (305 km) survey (Ref 8). The continuous negative film from the ROADRECON-70 survey is analyzed using a ROADRECON film projector. The projector can load a 400-foot (122 m) roll of 35-mm film and enlarge it ten times on the screen. Grid lines are projected simultaneously and the cracks and patches are scaled up relative to the grid size. The data is recorded manually on sheets and then transferred to a microcomputer through the keyboard. PASCO developed and used both negative and positive film to analyze distress data.

The developed film obtained from the ROADRECON-75 is analyzed using a film digitizer and by feeding the data into the computer. Software is used to plot the cross files and obtain maximum rut depth in each wheelpath. The computer output is plotted using a horizontal scale of 1:20 and a vertical scale of 1:1. It simulates a long straightedge and determines the maximum rut depth as the distance from the lowest point in the wheelpath perpendicular to the straight edge. The mean and maximum values of rut depths were calculated for each section.

The data from ROADRECON-85B is recorded on a paper chart and/or cassette magnetic tap. Rut depth is computed from the paper chart by the following procedure:

- o Divide the section into subsections of 200 feet (61 m).
- o Read the average rut depth in each subsection in the longitudinal direction (however, it is not as accurate as the rut depth from ROADRECON-75 (Ref 8)).
- o Compute the average rut depth over the section based on the rut depths calculated for all subsections.

The longitudinal profile data are computed from reading the wave height every 3.3 feet (1.0 m), starting from the beginning of the section. The horizontal scale is 1:20 on the paper chart and the vertical scale is 10 mm = 2 inches. If the data is recorded on the cassette magnetic tape, then it is automatically processed by the ROADRECON film/data analyzer (Ref 8).

During the field tests, paper charts were used with the scales mentioned above for ROADRECON-85B. The following information is plotted in a longitudinal direction.

- o Longitudinal profile.
- o Vehicle speed trace.
- o TCR (total cumulative ratio) count.
- o SD (standard deviation) of the longitudinal profile.

There is no other on-board data reduction. The plots are reduced in the office. PASCO's standard data analysis includes the computations of an overall index that takes into account cracking, rutting, and longitudinal roughness data.

Outputs

The following outputs were furnished by PASCO.

- Processed black-and-white positive film for all tests by ROADRECON-70. However, PASCO also used negative films in their data interpretation.

- 25 rolls of paper prints from 35-mm continuous negative films (enlarged four times) for all test sections.

- Paper prints (enlarged four times) from 35-mm negative film taken by ROADRECON-75 for rut depth (bound in two volumes with 21 prints per section, 8 sections in Volume I and 5 sections in Volume II) for tests made in the Austin, Texas area.

- Paper chart outputs for ROADRECON-85B for all test runs (43 tests included in the study and additional repeats for Sections 56 and 300).

- Paper chart outputs from ROADRECON-77 for 15 test runs (on eight sections located in Austin, Texas).

- Large computer-generated plots of cross profiles based on the ROADRECON-75 data.

- PASCO's standard output for all test sections consisting of:

    1. Road surface condition data tables for initial runs, repeat runs, and blind replicate runs (summarized by section). Each table includes crack ratio, rut depth, standard deviation (SD) of longitudinal profile, MCI pavement structure, and other inventory information.

2. Pavement performance chart that includes plots of MCI, SD, rut depths (mean for the section), and crack ratio for each section (separate plots for initial, repeat, and replicate runs).

3. Frequency tables for MCI and crack ratio data for all initial, repeat, and replicate runs.

4. Frequency diagrams for MCIs calculated for initial, repeat, and replicate tests.

5. List of sections which are candidates for repairs based on the criterion: 65.6 percent section length with an MCI of equal to or less than 4.0.

- A two-volume bound report on PASCO's participation in the study, containing: PASCO-ROADRECON systems, data reduction and retrieval equipment, summary of field tests, analysis of data, and 16 appendices which describe PASCO's capabilities and give a detailed description of the various ROADRECON series and standard outputs.

Field Notes

The field tests were carried out at night between 9:00 p.m. and 6:00 a.m. on July 21 to 23, 1986. No failures or breakdowns of the PASCO survey vehicle and ROADRECON instruments were observed. One driver and one operator were primarily responsible for all field tests, with some assistance from one other member of the Japanese delegation. The vehicle speed varied between 25 and 40 mph (40 and 60 kmph) during the tests. ROADRECON-70 and ROADRECON-85B were used for all test runs included in the study. However, ROADRECON-75 and ROADRECON-77 were used only on eight flexible pavement sections located in the Austin area.

Films were sent to Japan for developing and processing. ROADRECON-70 negative films were analyzed using a 35-mm film projector, manual data analysis using a grid, and manual entry using a keyboard. ROADRECON-75 films were digitized and reduced by computer software. The complete report and accompanying outputs with explanations were given to the researchers in October 1986.

Future Development

Table 30 shows the response of PASCO to the distress items typically used in the United States. At present, ROADRECON-70 is used to quantify distress data in two broad categories of cracking and patching; ROADRECON-75 and ROADRECON-85B are used for measuring rut depths. Obviously, it may require extra effort to develop the necessary software and distress identification methodology for measuring distress data as shown in Table 30.

PASCO is developing an automated ROADRECON film data analyzer for quantifying data from ROADRECON-70, -75 films and processing data from ROADRECON-77, -85B and other ROADRECON series. A laser disk-based system for pavement condition data and image retrieval is also under development (Ref 8). In addition, PASCO is also implementing a laser-based longitudinal profiling system.

GERPHO

The GERPHO (Groupe d'Examen Routiers Photographiques) device was conceived in 1975 by the Laboratoire Central Des Ponts et Chaussees (LCPC) and the Laboratsire Regional de Nancy. The GERPHO was built on the principle of operation used in continuous strip film photography of pavement surface by the Japanese equipment PASCO ROADRECON-70. GERPHO records the continuous image of the road surface on a 35-mm black-and-white film on a 1/200 scale. The GERPHO van is designed only for surface distress surveys. It is not capable of measuring rut depths or faulting in its present configuration.

GERPHO has been used for distress surveys in France for over a decade. The particular unit that participated in this study was seven years old. The van had traveled 160,000 miles (257,000 km) and performed

Table 30. Adaptability of ROADRECON systems to survey the recommended list of distresses (Ref 8).

Distress	Units of Measurement	ROADRECON Series -70	*-75	-77	-77B	-85	-85B	Remarks
Flexible Pavements:								
Alligator/Fatique Cracking	Square Feet	X	O	_	_	_	_	
Raveling	Square Fee	X	_	_	_	_	_	
Bleeding	Square Feet	X	O	_	_	_	_	
Block Cracking	Square Feet	X	O	_	_	_	_	
Longitudinal Cracking	Linear Feet	X	O	_	_	_	_	
Transverse Cracking	Linear Feet	X	_	_	_	_	_	
Potholes/Pothole Patching	Number	X	_	_	_	_	_	
Reflection Cracking	Linear Feet	X	O	_	_	_	_	
Lane/Shoulder Drop-Off	Mean Severity Level	O	X	_	_	_	_	
Lane/Shoulder Separation	Mean Severity Level	X	O	_	_	_	_	
Rutting	Square Feet	_	X	_	_	_	O	
Jointed Concrete Pavements:								
Blowups	Number	O	_	O	O	_	O	
Transverse Joint Spalling	No. of Joints	X	_	_	_	_	O	
Longitudinal Joint Spalling	No. of Joints	X	O	_	_	_	_	
Joint Load Transfer Associated Deterioration	No. of Joints	X	_	_	_	_	_	
Pumping and Water Bleeding	Highest Severity Level	X	_	_	_	_	_	
Longitudinal "D" Cracking	Linear Feet	X	O	_	_	_	_	
Transverse "D" Cracking	Linear Feet	X	_	_	_	_	_	
Longitudinal Cracking	Linear Feet	X	O	_	_	_	_	
Transverse Cracking	Linear Feet	X	_	_	_	_	_	
Lane/Shoulder Dropoff	Mean Severity Found	O	X	_	_	_	_	
Lane Shoulder Separation	Mean Severity Found	X	O	_	_	_	_	
Corner Breaks	Number	X	_	_	_	_	_	
Reactive Aggregate	Percent of Area	X	_	_	_	_	_	
Joint Faulting	Mean in Inches	O	_	_	O	_	O	
Continuously Reinforced Concrete Pavements:								
Transverse Crack Spalling	Linear Feet	X	_	_	_	_	_	
Longitudinal Crack Spalling	Linear Feet	X	O	_	_	_	_	
Transverse "D" Cracking	Linear Feet	X	_	_	_	_	_	
Longitudinal "D" Cracking	Linear Feet	X	O	_	_	_	_	
Pumping	Highest Severity	X	_	_	_	_	_	
Scaling, Map Cracking, Crazing	Severity Level	X	_	_	_	_	_	
Longitudinal Cracking	Linear Feet	X	O	_	_	_	_	
Longitudinal Joint Spalling	Linear Feet	X	O	_	_	_	_	
Longitudinal Joint Faulting	No. of Areas	O	X	_	_	_	_	
Punchouts	Number	X	_	_	_	_	_	
Construction Joint Deterioration	Number	X	_	_	_	_	_	
Reactive Aggregate	Percent of Area	X	_	_	_	_	_	
Lane/Shoulder Dropoff	Mean Severity Found	O	X	_	_	_	_	
Lane/Shoulder Separation	Mean Severity Found	X	O	_	_	_	_	
Longitudinal Profile Roughness:		_	_	X	X	X	X	

"X" indicates items well covered and "O" indicates items covered with other ROADRECON series.
* ROADRECON-75 covers items by sampling method.

38,000 miles (61,000 km) of photographic surveying according to the participating French delegation.

Equipment Description

Figure 18 illustrates two views of the GERPHO equipment. The equipment is set up aboard a mid-size Peugeot J7 van. It comprises:

- o A 35-mm running continuously camera.
- o A light source illuminating the pavement.
- o An electric generator set and a hydraulic unit isolated in the rear compartment.
- o A camera support.
- o A control panel and dashboard carrying controls and warning lights.

The following material is based on the technical information provided by the French delegation (Ref 9).

Camera. Three units comprise the camera: lens, mechanisms, and associated electronic elements. The camera box is custom made in France. It is fitted with a 14.5-mm Angenieux lens with an aperture of F3.5 and a mask having a slit 0.3-mm wide by 23-cm long, which makes it possible to check 15.2 inches (0.4 m) x 15.6 feet (4.8 m) of roadway. The mechanical unit includes a continuous running drive which is geared to the vehicle speed. Distance and timing marks are recorded on the film by two marker tubes. The magazines hold 400 ft (120 m) of 35-mm film which will film 15 miles (24 km) of pavement. The ASA200 film is Kodak Double X negative #5222 (black and white). The mechanical and optical units are contained in a housing with a protective cover. There is an end-of-film indicator and a meter that shows the length of the film exposed.

The film is driven by an impulse motor actuated by the Rhythm-O-Start and by a source of impulses. The impulse unit is coupled to the gear box of the van. This system ensures synchronization between the advance of the film and the movement of the vehicle, in the ratio of 1/200. There

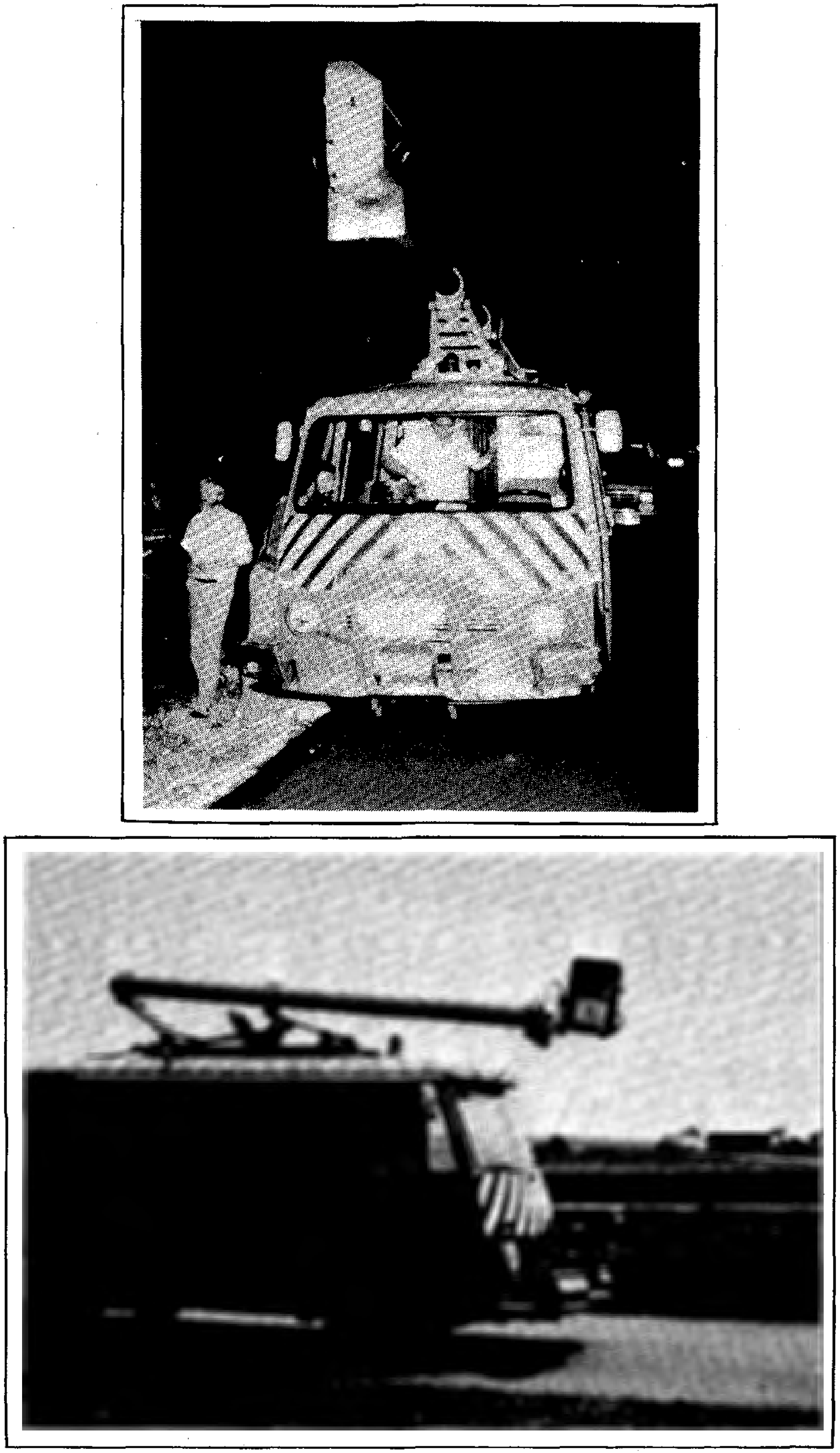


Figure 18. Night (top) and day (bottom) views of GERPHO.

are markers for special features (structures, mile posts, etc.) and a marker is placed automatically on the film every 100 m of pavement. There is one meter between sprocket holes on the film.

Camera Support. The support is designed to bring the 35 mm camera in a position so that the lens is 9.5 feet (2.9 m) vertically from the ground and 3.3 feet (1 m) in front of the light source so that the angle of lighting is 30°. The camera support is hydraulically retracted and extended for ease of loading the magazine from the measuring position.

Light Source. The intensity of the light source varies with the vehicle speed for uniform exposure of the film. The system uses five 1000 watt iodine projectors which provide a maximum light intensity at an angle of 30°. The surface of the pavement is illuminated uniformly over about 11 square feet (16 feet by 0.7 feet) or 1 square meter (5 m by 0.20 m), vertically below the lens. The vehicle speed may vary from 5 to 40 mph (8 to 60 kmph), so a thyristor light graduator is used to control the lamps along with control pulses from the van gear box.

Generator Set and Hydraulic Unit. These units are placed at the rear of the van, in an insulated and ventilated compartment, along with the starter battery for the generator and cooling systems. The generator set consists of a 10 kVA alternator supplying three-phase current at 220V and provides the electric power necessary for the whole installation. A hydraulic unit actuates the jack controlling the camera support.

Control Panel and Dash Board. The monitors and controls for remote operation are: camera servo, light graduators, generator set controls, hydraulic unit control, and indicator lights. In addition, there are five ammeters that indicate proper functioning of the projectors and six warning lights on the dash board for: vehicle moving too slow, normal speed, vehicle moving too fast, loss of synchronization due to improper functioning of the camera, hectometric flash (lights every 100 m of pavement), and end of film indicator.

Additional Capabilities. GERPHO is designed for surface distress only. France has opted for a specific purpose design of its pavement condition monitoring methods. Consideration of additional parameters is discussed later in this section.

Operating Procedure

The photographic survey is performed at night by two operators, at a speed of up to 60 kmph (approximately 40 mph). The two operators are responsible for: connecting all the components, driving the vehicle, keeping a check on the functioning of the apparatus, loading the camera cartridges, and completing the record sheet.

To avoid loss of time during the survey in this study, eight cartridges were prepared in advance. In this way, experience has shown that under optimum conditions it is possible to photograph 60 to 125 miles of pavement per night (100 to 200 km), according to the operators. The French team also noted it was obvious that the efficiency of the equipment drops when the sections are short and dispersed (Ref 9) which was the case of the present study.

The photographic survey operation causes practically no inconvenience to other road users, since it is performed at night, and the vehicle, running along normal traffic lanes, forms part of the general traffic. Water, snow, or rain are the only operating restrictions.

Data Processing and Interpretation

The data processing is carried out in two stages: 1) developing and editing of the film in the photo laboratory, and 2) visual analysis of the film with a viewing table and the distress data reduction with an operating station.

As illustrated in Figure 19, the processed negative films are placed on a viewing table. A screen 12 inches by 19 inches (0.3 m by 0.5 m) shows two films simultaneously, representing the equivalent of 65 feet (20 m)

Figure 19. Viewing table and operating station used for office visual analysis of films and data reduction.

with a magnification of four. The analysis of the GERPHO films in terms of the nature of distress goes through a process of human interpretation. In the case where two films are operated simultaneously, the information is collected at a rate of 10 to 12 miles per day for roads with relatively large degradations, according to the French delegation (Ref 9). The system allows for simultaneous reading of two films representing two different road lanes. These lanes could be:

- o The inside and outside lanes on one side of the road (heading in the same direction).
- o Lanes heading in two different directions on the same road.
- o The same lane seen on two different occasions (different years).

The progression of distress and the rates of deterioration are analyzed by comparing the most recent film with a previous film. A forward/backward step-by-step shifting of the films on the viewing table allows a step equivalent to 20 meters of the road. A slow or fast speed continuous shifting of the films is another feature of this table. A display meter of the curvialinear abscissa allows the exact positioning of the details of the films. As an option, an instant camera such as a Polaroid can be used to take photos (Ref 9). However, the French operator who demonstrated the table to the researchers mentioned that the use of this option is not a general practice in France.

The data reduction of the GERPHO films plays an important part in the maintenance of the national roads and highways in France. Both the hardware and software could be adapted to fit the needs of the agency using the equipment (Ref 9). The operating station used in Austin, Texas was equipped with a portable microcomputer with a floppy diskette, a special keyboard, a CRT monitor, and a printer. The French team brought the software packages, using the French LCPC methodology, for the two major types of roads inspected in France: asphalt pavements and jointed concrete pavements.

The software handles both inventory and distress data. The keyboard is equipped with a special template for each pavement type dedicating certain keys to the various types of distresses.

Data interpretation for asphalt pavements is done by elementary zones each 65 feet (20 m) long. The distress is integrated by film and over 20 meters. (Example: for 20 meters, the operator sums the number of potholes). Table 31 shows distress types used in the standard French method.

The two types of outputs that are produced are:

- o Results listings
  1. An exhaustive list which represents a transcription of the distress listings for 20-meter zones.
  2. A synthesis list in which the elementary results are regrouped and synthesized over 100-meter stretches.

- o Synthesis list in which the results, grouped in 100 meter stretches are printed.

Table 32 shows distress types used in the standard French outputs. For each distress (except pumping), entries are made for those which are repaired and those which are not.

For jointed concrete pavements, the following two principles are used:

- o The entry of the distress is done slab by slab. Results are given only on slabs where there is distress.

- o In the case where itineraries are followed through in time, the system makes it possible to collect only data developed in relation to a previous collection. In this case, the previous film is coupled with the film to be checked.

Table 31. Distresses for asphalt pavements measured by GERPHO based on the French method.

Identification of the Distress	Identification Criteria and Quantification Mode
Alligator Cracking	Alligator cracking is shown in square meters
Longitudinal Cracks	
o In wheel path (I.W.P.)	Length given in meters
o Out wheel path (O.W.P.)	Length given in meters
Open Joints	
o Longitudinal (LONG)	Length in meters
o Transversal (TRAN)	All or nothing - yes or no
Transverse Cracks	
o Single	Quantity
o Multiple	Quantity
High Severity Potholes	Quantity
Pumping	Quantity
Stripping	Length in meters
Bleeding	Length in meters
Low Severity Potholes	Area in square meters
Patching	
o Sealed Transverse Cracks	Quantity
o Longitudinal Cracks	
a) Total length (TOTAL)	Total length in and out wheelpaths as well as surfacing section
b) Sealed length (S.L.)	Same as above. Longitudinal cracks that have been repaired
o Patching (PATCH)	Area in square meters

Table 32. Distresses for jointed concrete pavements measured by GERPHO based on the French method.

Designation of the Distress	Primary Identification Criteria
Longitudinal Joint Cracks	Sawing was not total, hence cracking at the level of the joint
Transversal Crack	Crack with perpendicular directional tendency at the longitudinal joints
Diagonal Crack	Crack with slanting directional tendency linking a transversal joint to a longitudinal joint at a distance of more than one meter from the corner of the slab
Longitudinal Crack	Crack with parallel directional tendency at the longitudinal joints
Spalling	On longitudinal or transversal joints
Corner Break	Distance from the break at the corner the slab smaller than 1 meter (if greater than 1 meter, it will be identified as a diagonal crack)
Pumping	All or nothing: yes or no

Two types of outputs are produced:

- o A table that shows the listing collected slab by slab.
- o A table that shows the summary output.

The GERPHO team also developed software to produce reports using distress categories commonly used in the United States for asphalt, jointed concrete, and continuously reinforced concrete pavements. Examples of these outputs, as well as the standard French output, are included in Appendix B.

<u>Outputs</u>

The following outputs were generated by GERPHO for this study.

- o The processed black-and-white negative films for all tests. This is the standard output.

- o A two-volume report.

The first volume of this report contains information describing GERPHO, the French method of distress identification and reports, and the adaptation to the distress types typically used in the United States. In addition, five paper prints from negatives, sample data sheets, and considerations related to commercial availability and a United States version of the GERPHO are presented.

The second volume of the report contains appendices for distress data output in the following sequence:

- o Tables of summary outputs for all sections based on the French method.

- o Tables of detailed outputs for each section using the distress list on Table 4 (in U.S. format). This implies that for each section and one test run, there are ten outputs for the subsections identified from 0 to 9.

Field Notes

The field tests were carried out during the night between 9:00 p.m. and 5:30 a.m. on July 17 to 20, 1986. No failures or breakdowns of the GERPHO equipment were observed during these tests. One driver and one operator were responsible for all field tests. The driver maintained uniformity in the vehicle speed of about 40 mph (60 kmph) during the field tests.

The 35-mm films were developed in Austin by the French delegation. The quality of film was adequate. Several test sections were analyzed in Austin using the viewing table, a portable microcomputer with a floppy diskette, a special keyboard, and a printer. Several ARE Inc staff members saw the demonstration of data analysis and made independent interpretations of some sections. It took a few hours to learn the operation of the viewing table, collect, and process data. It also took some time to get used to reading negative film. Once trained to identify distresses on negative, the data interpretation and processing is very rapid. It was easy to go back to any section on film. The French team stated that the quality of the film could be even better if processed in their photo laboratory in France.

Future Development

MAP Inc intends to assemble a GERPHO using an American-made vehicle for a potential client in the United States (Ref 9). It will commission the equipment, provide a comprehensive operator's manual, and train the personnel. The new machine will be equipped to measure rutting and faulting, according to the French delegation (Ref 9).

The adaptability of the software for interpreting distress data and generating reports using typical distress information has been demonstrated by the GERPHO participants during this study. Their response to the items of the recommended distress list is presented in Table 33.

ARAN

The Automatic Road Analyzer (ARAN) is produced by Highway Products International, Inc. Eight ARAN orders have been completed or are in process (Ref 14). The ARAN Model III, used for the field tests, is shown in Figure 20. Field tests for the ARAN were conducted during the day on September 4 to 8, 1986. The information presented here is based on References 14 and 11 and discussions with the ARAN team.

There are several measurement options available with the ARAN (Ref 11). Pavement distresses, observed through the windshield, are recorded using two rating keyboards. Ultrasonic transducers are installed on a front bumper bar to measure rut depth. Rut bar extension "wings" enable measurement of a 12-foot (3.6 m) lane width. Rutting is measured for the left and right wheelpath. The sensor in the middle serves as a centerline and, on either side of this centerline, the two highest points are found. A line is "drawn" through the two highest points and a perpendicular from this line to the low point is considered to be the rut depth. This method is similar to using a six-foot (1.8 m) straightedge in each wheelpath in the field.

Grade and crossfall measurements are possible through the addition of gyroscopes. A directional gyroscope is used to establish a curve radius. Rear axle and body-mounted accelerometers measure vertical accelerations and are used to provide roughness data. Two video logging cameras are used to provided an integrated picture of right-of-way and pavement surface images. Application software provides output in tabular and colored graphical formats.

Equipment Description

The ARAN condition/inventory survey system is self-contained in a van which operates at 30 to 55 mph (48 to 88 kmph). An on-board power supply

Table 33. Adaptability of the GERPHO system to survey the recommended list of distresses (Ref 9).

1. <u>FLEXIBLE SURFACES</u>

Distress Type	Adequately Measured From Film in Terms of Severity and Quantity	Additional Equipment Required
Alligator/ Fatigue Cracking	X	
Ravelling	X	
Bleeding	X	
Block Cracking	X	
Longitudinal Cracking	X	
Transverse Cracking	X	
Potholes/ Potholes Patching	X	
Reflection Cracking	X	
Lane/Shoulder Dropoff		⊗
Lane/ Separation	X	
Rutting		⊗

⊗ All these distresses are to be measured with a special attachment to the GERPHO.

XX Faulting will be measured with the APL Longitudinal Profile Analyzer towed behind the GERPHO, or any other vehicle.

Table 33. Adaptability of the GERPHO system to survey the recommended list of distresses (Ref 9) (continued).

2. JOINTED CONCRETE PAVEMENTS

Distress	Adequately Measured From Film in Terms of Severity and Quantity	Required
Blow-ups	X	
Transverse Joint Spalling	X	
Longitudinal Joint Spalling	X	
Joint Load Transfer Associated Deterioration	X	
Pumping and Water Bleeding	X	
Longitudinal "D" Cracking	X	
Transvere "D" Cracking	X	
Longitudinal Cracking	X	
Transverse Cracking	X	
Lane/Shoulder Dropoff		⊗
Lane Separation	X	
Corner Break	X	
Reactive Aggregate	X	
Joint Faulting		XX

⊗ All these distresses are to be measured with a special attachment to the GERPHO.

XX Faulting will be measured with the APL Longitudinal Profile Analyzer towed behind the GERPHO, or any other vehicle.

Table 33. Adaptability of the GERPHO system to survey the recommended list of distresses (Ref 9) (continued).

3. CONTINUOUSLY REINFORCED CONCRETE SURFACES

Distress	Adequately Measured From Film in Terms of Severity and Quantity	Additional Equipment Required
Transverse Crack Spalling	X	
Longitudinal Crack Spalling	X	
Transverse "D" Cracking	X	
Longitudinal "D" Cracking	X	
Pumping	X	
Scaling, Map Cracking, Crazing	X	
Longitudinal Cracking	X	
Longitudinal Joint Spalling	X	
Longitudinal Joint Faulting		XX
Punch-outs	X	
Construction Joint Deterioration	X	
Reactive Aggregate	X	
Lane/ Shoulder Dropoff		⊗
Lane/ Shoulder Dropoff	X	

⊗ All these distresses are to be measured with a special attachment to the GERPHO.

XX Faulting will be measured with the APL Longitudinal Profile Analyzer towed behind the GERPHO, or any other vehicle.

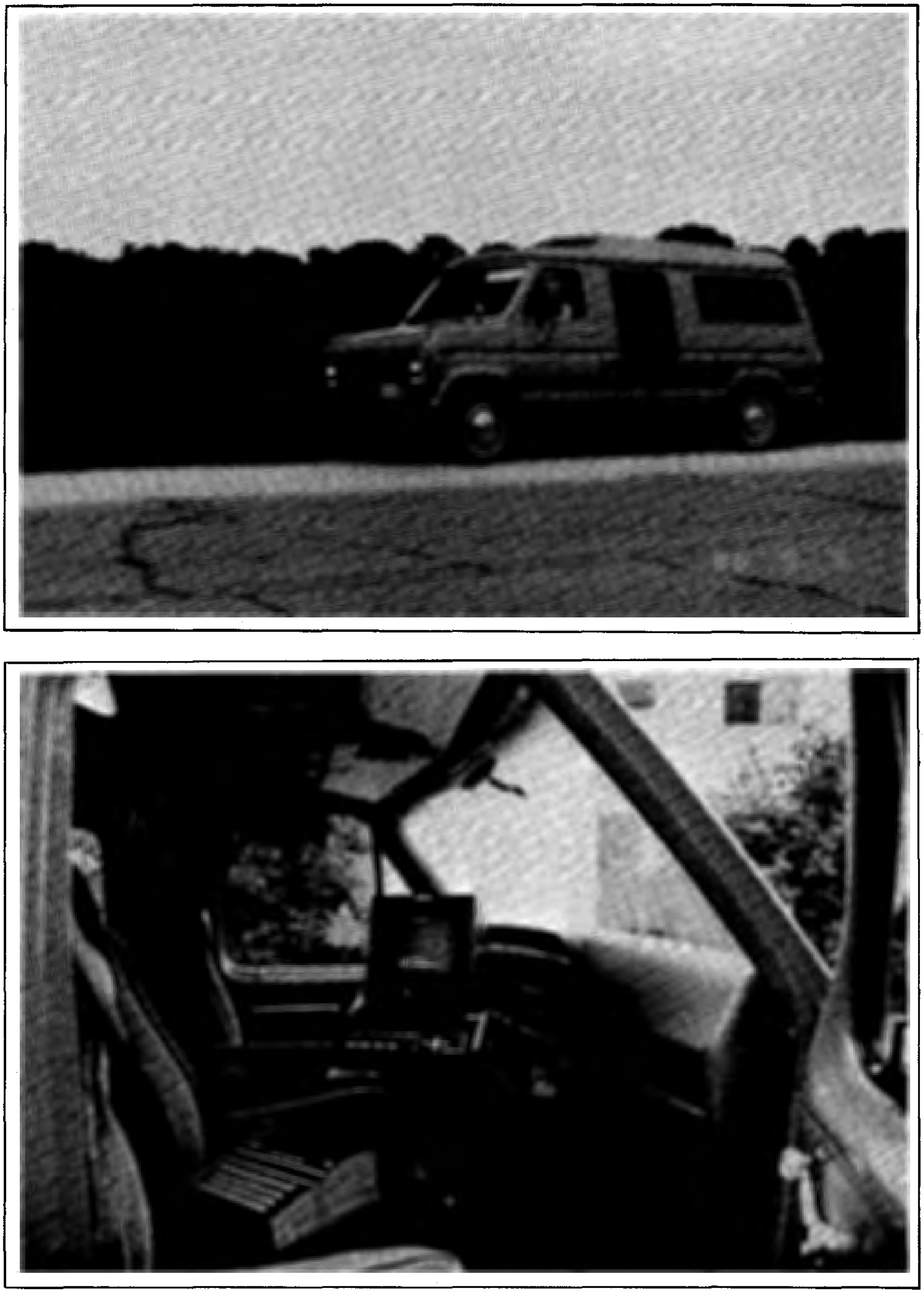


Figure 20. A side view of the ARAN van (top) and systems monitor and control keyboard (bottom).

consists of two batteries and alternators. A transmission driven Distance Measuring Instrument (DMI) is used. Other hardware included is a video system, microcomputer, accelerometer, surface distress rating keyboards, gyroscope, and ultrasonic sensor profile bar, all of which are described below.

Two plug-in condition rating keyboards are used to enter surface distress data onto the magnetic recording medium while driving at 30 mph (48 kmph). Header information and traveled distance is synchronized with the distress data. Eight special event keys are used for data such as landmarks, bridges, etc. This data is entered adjacent to the distress data on the magnetic recording medium. The most recent data is displayed on a back-lit liquid crystal until the data is updated or cleared.

A front bumper-mounted ultrasonic bar is used to measure the transverse profile. The bar is 6 to 12 feet (1.8 to 3.7 m) in length, depending on the fold-up wing extensions of 1 to 3 feet (0.3 to 0.9 m) on each side of the bar. The ultrasonic sensors are spaced 12 inches (0.3 m) apart. The sensors operate at approximately 50 kHz. A reference sensor with a fixed target is used to correct sensor data to compensate for temperature and humidity changes. Each sensor is recorded to computer memory after being analog to digital processed.

The on-board microcomputer is an IBM PC-AT, 7532 12-volt DC System, including ARAN interface modules. There is a 1904K memory on board for data storage. The collected data is stored in RAM and periodically transferred to a 1.2 MB 5-1/4 inch floppy disk. All of the data is recorded on machine-readable magnetic medium in raw data form. The data collection may be automatically started but must be manually terminated. The data is automatically transferred to a floppy disk. According to the manufacturer, there is software which adjusts the data to compensate for speed variations during data collection.

There are two video logging cameras (Figure 21). One camera is mounted on the rear of the van and produces an image of the pavement surface. The camera is a Sony DXC-M3 with a Panasonic special effects

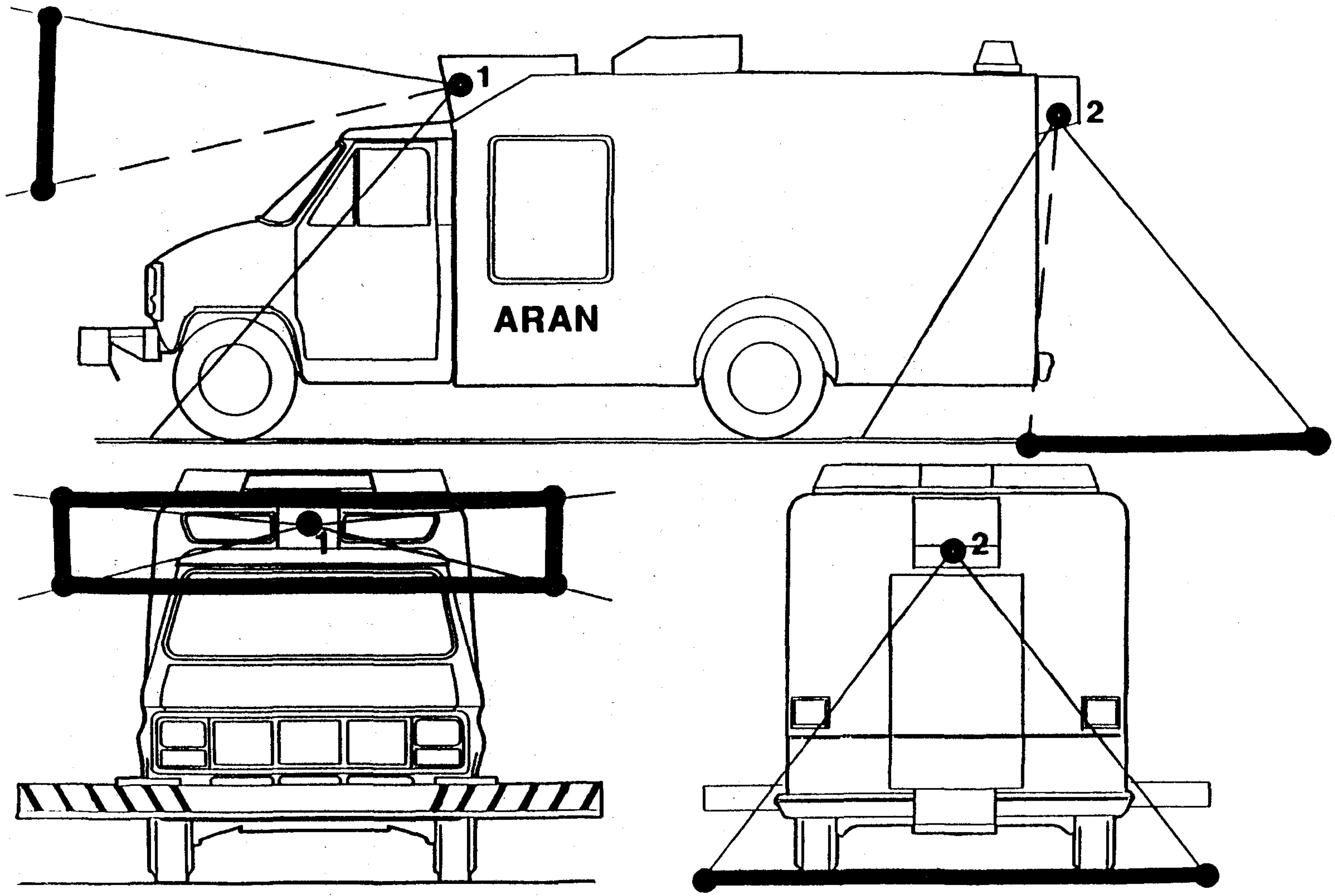


Figure 21. Schematic illustrating right-of-way and road surface view captured by ARAN'S video equipment (Ref 11).

generator WJ-4600C. A Panasonic NV 8420 Recorder is used. A wide angle lens is used. Thirty picture frames per second are taken. Each frame indexes 2.5 feet (0.8 m). The shutter takes 30 stills per second. The camera is black and white. The second camera is mounted inside the van and provides a through-the-windshield roadway right-of-way view in color. In the rear work area of the van, a video monitor displays the pictures as they are being recorded. When viewing the video picture, the two camera images are merged, with the right-of-way image being inserted into the top one-third of the pavement surface view. Header information is superimposed over the camera right-of-way image.

Longitudinal roughness is measured using an accelerometer that is mounted on the rear axle of the van. The accelerometer measures vertical accelerations that represent the average of two wheelpaths. Roughness may be measured between 25 and 55 mph (40 to 88 kmph). A pitch and roll gyroscope is used to measure pavement longitudinal grade and crossfall. Pitch and roll are sampled separately every 13.1 feet (4.0 m). A precision directional gyroscope is used to measure the actual directional heading from zero to 360 degrees. The gyroscope resolution, timing, and response frequency is proprietary information. The ARAN vehicle must sit stationary, about five minutes, when the gyroscope is powered down.

Operating Procedure

The calibration of the DMI is checked before starting field tests. One ultrasonic sensor bar is used to calibrate sensors to automatically correct measurements for air density variations. Diagnostic software is provided which permits the operator to simulate the data collection mode to verify that a specific subsystem is functioning properly. Calibration software is provided to check for the operational status before and after tests. A work area is available for the operator to perform data checks and video verification before returning to the office.

Three people are used to operate the ARAN system. Two operators perform a subjective distress survey through the windshield at 30 mph (48 kmph) and use the two keyboards to record data. Video taping is performed simultaneously, as well as rut depth and roughness measurements and the use of gyroscopes. The survey is performed in the daytime. Moisture is an operating constraint. Like other automated high-speed devices, traffic control is not required for the ARAN.

The two operators who rate surface distresses through the windshield need extensive training and experience to learn the explanations of various codes used for severity and extent of each distress. An example of the codes is shown in Figure 22. During the field testing, the two operators had memorized this manual and did not need to refer to the manual during the field tests.

Data Processing and Interpretation

The field data is brought into the office on an IBM floppy disk. The disk is first cleaned and then the analysis is performed using HPI's software. The data report consists of the resulting hard copies.

The first part of the data report consists of a listing of eleven different distresses reported to be found on the pavement section with codes representing the severity and extent of each distress. The first number in the code (0, 1, or 2) represents slight, moderate, or severe levels of severity. The second number in the code (0, 1, 2, 3, 4, or 5) represents the extent which is usually a range. An explanation of these numbers is given in HPI's condition rating descriptions (Ref 15). The page explaining transverse cracking for flexible pavements is presented as Figure 22. For an example, a code of "1-4" would indicate moderate cracking with a spacing of 20 to 50 feet (6 to 15 m) per sample, with the sample being 180 feet (60 m) for urban roads. This system becomes more complex if a code of "1-1" is reported. This indicates a crack spacing of greater than 250 feet (76 m) per 180-foot (60 m) sample. In addition, the sample distance is not the same as the stations reported in the data output. Distress data is reported in 0.02-mile (32 m) stations in the data output. The manufacturer states that the setup of the keyboards and the interpretation of what is recorded may be user-defined.

TRANSVERSE CRACKING

SAMPLE INTERVAL - sampling is taken at 100 m (300') intervals - RURAL
- sampling is taken at 60 m (180') intervals - URBAN

KEY	DESCRIPTION	SEVERITY	DENSITY	CRACK SPACING BETWEEN CRACKS/SAMPLE
F-00	- No observation	None	None	0
F-01	- <½" (<13 mm) wide	Slight	0% → 4%	>250'/SAMPLE (>76 m/SAMPLE)
F-02	- <½" (<13 mm) wide	Slight	4% → 10%	100' → 250'/SAMPLE (30 m → 76 m/SAMPLE)
F-03	- <½" (<13 mm) wide	Slight	10% → 30%	50' → 100'/SAMPLE (15 m → 30 m/SAMPLE)
F-04	- <½" (<13 mm) wide	Slight	30% → 60%	20' → 50'/SAMPLE (6 m → 15 m/SAMPLE)
F-05	- <½" (<13 mm) wide	Slight	60% → +	0' → 20'/SAMPLE (0 m → 6 m/SAMPLE)

KEY	DESCRIPTION	SEVERITY	DENSITY	CRACK SPACING BETWEEN CRACKS/SAMPLE
F-10	- No observation	None	None	0
F-11	- ½" → 1" (13 mm → 25 mm) wide	Moderate	0% → 4%	>250'/SAMPLE (>76 m/SAMPLE)
F-12	- ½" → 1" (13 mm → 25 mm) wide	Moderate	4% → 10%	100' → 250'/SAMPLE (30 m → 76 m/SAMPLE)
F-13	- ½" → 1" (13 mm → 25 mm) wide	Moderate	10% → 30%	50' → 100'/SAMPLE (15 m → 30 m/SAMPLE)
F-14	- ½" → 1" (13 mm → 25 mm) wide	Moderate	30% → 60%	20' → 50'/SAMPLE (6 m → 15 m/SAMPLE)
F-15	- ½" → 1" (13 mm → 25 mm) wide	Moderate	60% → +	0' → 20'/SAMPLE (0 m → 6 m/SAMPLE)

KEY	DESCRIPTION	SEVERITY	DENSITY	CRACK SPACING BETWEEN CRACKS/SAMPLE
F-20	- No observation	None	None	0
F-21	- >1" (>25 mm) wide	Severe	0% → 4%	>250'/SAMPLE (>76 m/SAMPLE)
F-22	- >1" (>25 mm) wide	Severe	4% → 10%	100' → 250'/SAMPLE (30 m → 76 m/SAMPLE)
F-23	- >1" (>25 mm) wide	Severe	10% → 30%	50' → 100'/SAMPLE (15 m → 30 m/SAMPLE)
F-24	- >1" (>25 mm) wide	Severe	30% → 60%	20' → 50'/SAMPLE (6 m → 15 m/SAMPLE)
F-25	- >1" (>25 mm) wide	Severe	60% → +	0' → 20'/SAMPLE (0 m → 6 m/SAMPLE)

NOTE: F-01, F-11 or F-21 are used for individual work identification in urban situations.

Figure 22. ARAN'S condition rating description for transverse cracking on flexible pavements (Ref 15).

At each station, a surface distress index (SDI) is also reported. The SDI is a number between 0 and 5 representing a weighted average of the eleven distresses, with a 5 indicating a pavement section with none of the eleven distresses present.

The second part of the data report consists of a summary report of the surface distress indices. This summary is a colored plot of the surface distresses for the pavement section.

The surface distress report for Section C5 was not given because the file was lost in the transfer from the on-board RAM to the disk (cause was unknown). Also, several rigid sections were first analyzed as flexible. This error was discovered about a week after the data output was completed. The data for these sections had to be reanalyzed.

The second part of the output was information on rutting. Rut depth was measured and reported every 0.02 miles (32 m) for the left and right wheel paths. The percent over 0.50 inches (12.7 mm) and the percent over 0.25 inches (6.4 mm) are also given. The mean depth for the section is presented along with the standard deviation.

The next part of the report presents the measured roughness and Present Serviceability Indexes (PSI) at 0.02-mile (32 m) intervals. The mean and standard deviation for the section is presented, along with the maximum and minimum PSIs for the section.

The last part of the report consists of a Present Serviceability Index summary. This summary is similar to the surface distress index summary. A colored plot of the PSIs found at each station of the section is given.

<u>Output</u>

The output of ARAN included three videotapes in VHS format. Data reports, produced in the office, were about five pages long for each 1000-foot (305 m) test section. The reports consisted of the following items:

a listing of the distresses reported to be found on the section with a composite surface distress index, a colored plot of the surface distress indices, information on rut depth, roughness data and Present Serviceability Indexes, and a colored plot of the PSIs. Seven floppy disks containing the raw field data were also provided.

In addition to conducting surveys of the required test sections, HPI tested a 4.5 mile (7.2 km) section of Blake Manor Road near Austin, Texas. This was done to show the usefulness of ARAN's reports on longer sections. Also, rut depth measurements were done at 30 mph (48 kmph) and 50 mph (80 kmph) to include additional repeatability runs. However, only the rut depth measurements taken at 30 mph (48 kmph) were used for the data analysis in this report.

Field Notes

The system encountered several problems during the field testing. On September 2, 1986, the ARAN vehicle was run to check the calibration of the distance measuring device (DMI). The DMI malfunctioned and was fixed the following day by an HPI engineer. The first day, on September 4, 1986, the operator forgot to remove the dust caps from the ultrasonic sensors prior to testing Section 300. This resulted in a loss of rut depth data on two sensors. The caps were removed and the section was rerun. The same day, it rained for about 30 minutes. Although the dust caps were in place on the sensors, five out of the seven sensors became inoperable. There was evidence of water above and below each sensor mount. Efforts to dry the sensors failed so new sensors were installed. The repair time was approximately 90 minutes. On September 5, 1986, testing was interrupted because of rain and wet pavement conditions. On September 6, 1986, it was discovered that the rut depth measurements taken on the previous day were invalid. One of the sonar boards had failed. After it was repaired, the measurements were rerun on September 8, 1986.

In summary, the ultrasonic sensors used to measure rut depths were very sensitive to moisture. Problems occurred several times during testing, and sensors, driver boards, and associated electronics had to be replaced. The manufacturer later stated that because of the moisture sensitivity problems revealed during this study, corrective steps have been taken to improve the sensors and the sensor caps.

Playing back and monitoring of recorded video tapes can not be adequately done on home video players. A high resolution, professional quality video monitor and video player, with four heads is required for this purpose.

LASER RST

The Laser RST originates from Sweden and is used by IMS in North America. Two RST units are presently in service in the United States. The unit used in the field tests was completed in mid-1986 and had traveled over 31,000 miles (50,000 km). Figure 23 shows the RST device used in this study. The material presented here is based on Reference 13 and discussions with the IMS team.

Principle of Operation

The RST uses eleven laser sensors mounted on the front of the van as illustrated in Figure 24 for measuring distress data. All eleven lasers supply data to measure rut depth. The on-board processing computer simulates a transverse profile and records the deepest rut every 4 inches (10 cm) using the wire method. Lasers are also used for texture measurements. Four lasers supply signals for measuring cracks and categorizing cracks according to its width and depth. The special crack-measuring cards essentially determine that amplitudes greater than the texture are cracks. Depth and width of cracks are stored in several categories in real time. Longitudinal and alligator cracking and patches are identified and recorded visually by using eight manual switches.

Equipment Description

The RST is mounted on a dedicated van, powered by the van battery and the Onan generator. Other components are listed below.

Figure 23. Side view of IMS Laser RST (top) and laser support beam and distance recorder (bottom).

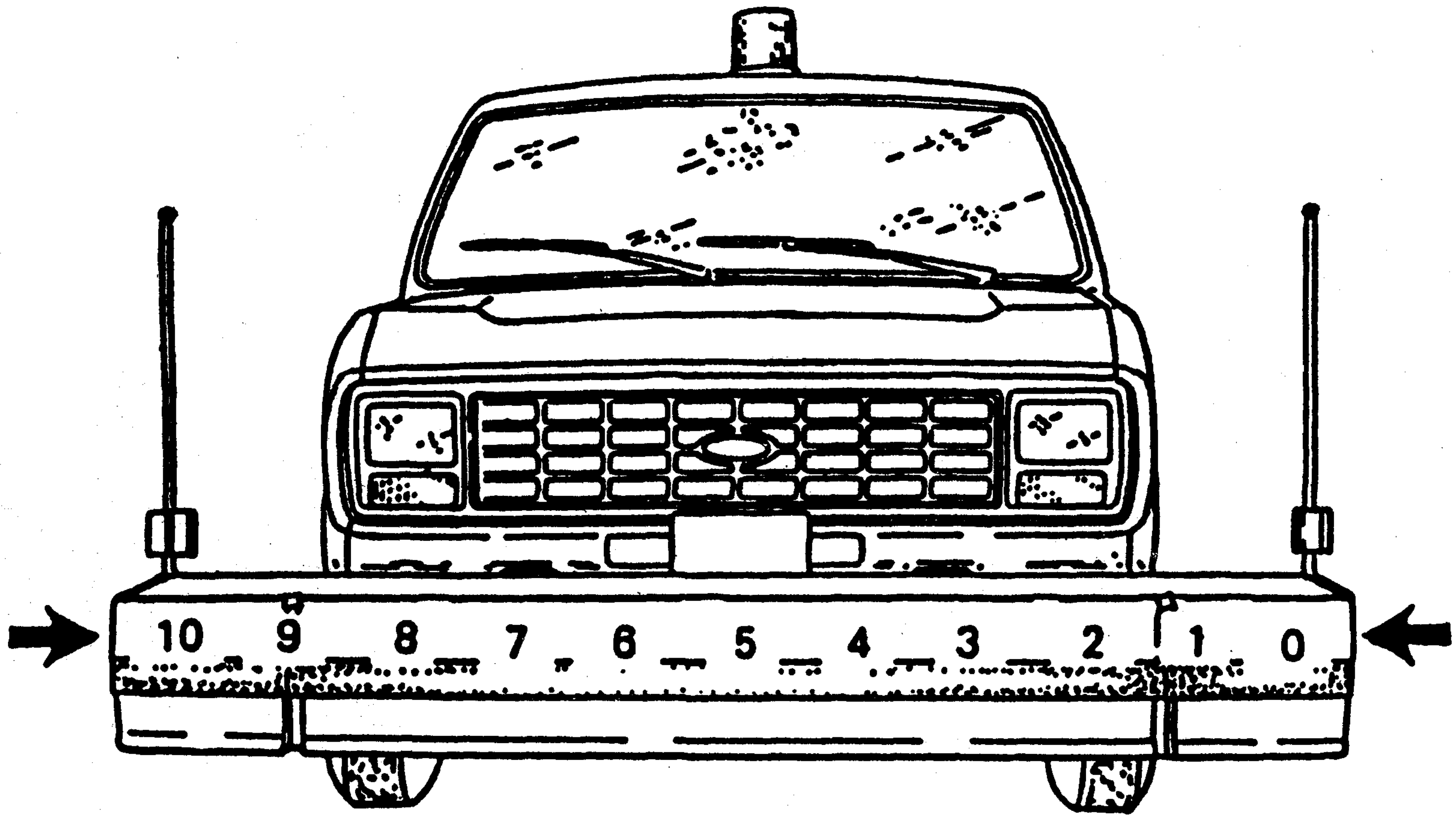


Figure 24. Schematic illustrating the eleven lasers mounted on front bar of IMS' Laser RST (Ref 13).

Laser Bar. Eleven lasers (Selcom/AB) are mounted on a support beam at the front as illustrated in Figure 24. The operation of a laser sensor is shown in Figure 25. The lasers are numbered from 0 to 10 looking from the drivers position. Laser No. 10 can easily be turned off by the operator. Regular lasers 1, 3, 5, 7 and 9 operate at 16 kHz. Angled lasers 0 and 10 also operate at 16 kHz and are positioned at a 45 degree angle outward to measure a width of 10 feet (3.1 m) with the laser bar only 8.5 feet (2.6 m) wide. Combination lasers 2, 4, 6 and 8 operate at 32 kHz. Each laser is covered by a shield during long transport distances and has a red indicator lamp that glows when voltage is supplied to the laser.

Distance and Velocity Measurement. An optical strobe actuated pulse transducer sends 36 five-volt pulses per revolution of the tire to a special measuring card to determine distance and velocity.

On-Board Computer System. At present, the RST uses an on-board Primal Data 2000 computer with 64k memory. Programs are on one 8-inch floppy disk and the data is recorded on another 8-inch floppy disk. A printer and terminal are also provided.

Subjective Switches. Types of cracks are identified by using eight three-position toggle switches. The laser must cross a crack to read it, therefore, longitudinal and edge cracks and alligator cracking are rated subjectively by one operator with the switches. Table 34 shows various items rated subjectively using these toggle switches.

Inventory Computer. An on-board IBM-PC computer is used to collect inventory data such as: section number, object number, beginning and ending locations, traffic classifications, pavement type, direction of travel, and lane tested.

Accelerometer. A Sunstrand accelerometer is used to determine longitudinal profile. The accelerometer is mounted in the left (inside) wheelpath. Vertical movement of the laser is calculated from the accelerometer measurement. Vertical movement of the van and laser is

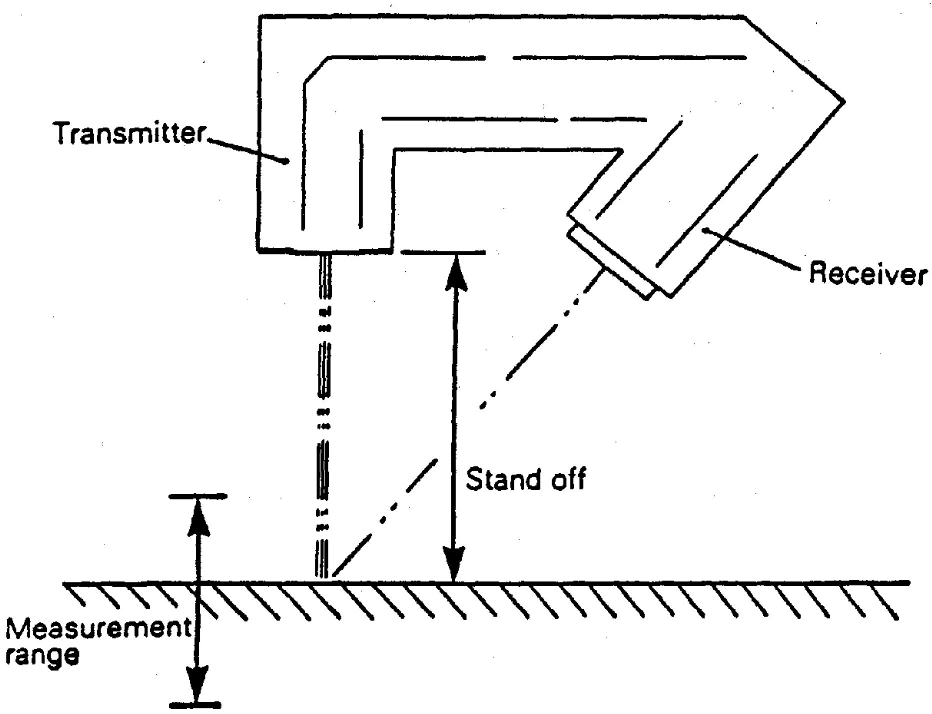


Figure 25. Principle of laser operation (Ref 13).

Table 34. Subjective ratings using toggle switches (Ref 13).

SWITCH #1	DRAINAGE	
	1- Curb and gutter or 5' to 8' ditch with storm sewers.	
	2- Greater than 2' ditch.	
	3- Less than 2' ditch.	
SWITCH #2	SHOULDER TYPE	
	1- Curb and gutter or 8' paved.	
	2- 8' paved down to 2' paved.	
	3- Less than 2' paved.	
SWITCH #3	SHOULDER CONDITION	
	1- Good	
	2- Fair	
	3- Poor	
SWITCH #4	ALLIGATOR CRACKING	
	1- None	
	2- Showing small patches of alligator cracking (up to 33%).	
	3- More than 33% alligator cracking.	
SWITCH #5	EDGE CRACKING	
	1- None or a single crack less than 1/4".	
	2- Multiple cracks extending over 2' from pavement edge but no more than 3'.	
	3- Multiple cracks extending over 3' from pavement edge with outermost area begining to alligator.	
SWITCH #6	LONGITUDINAL CRACKS	
	1- None	
	2- Less than 1/2"	
	3- Greater than 1/2"	
SWITCH #7	RANDOM CRACKING	
	1- None	
	2- Less than 1/2"	
	3- Greater than 1/2"	
SWITCH #8	EDGE PROFILE	
	1- Shoulder even with pavement.	
	2- Shoulder lower 1" or more.	
	3- Shoulder higher 1" or more.	

recorded with the laser. With these measurements at every 65 feet (20 m), a true profile is calculated in the time domain.

Operating Procedure

The Laser RST can be operated day and night. Daytime operation is necessary to collect subjective ratings of several distress items not identified by the lasers. Three operators are required. Their duties involve: driving, operation of subjective switches, operation of inventory computer, and starting and ending of test sections. The operator of the subjective switch also presses the button to start the objective measurements. The RST is operated at 50 mph (80 kmph). Calibrations of lasers, accelerometer and the distance measuring instrument (DMI) are performed regularly.

Calibration of Lasers. A straightedge (calibration bar) is placed under the eleven lasers and then a computer program is used which stores the distance from the eleven lasers to the calibration bar (in units of 1/16 mm). This program establishes a straight reference line for rut depth calculations. To test whether or not a laser is working properly, approximately 300 readings to the calibration bar are recorded and the standard deviation is calculated and checked (this is done automatically for each laser). This procedure takes about 10 minutes and is performed daily. If dirt or mud covers the laser while testing, an invalid light will illuminate (one light for each laser). However, it has not occurred in the recent past, according to the RST team.

Calibration of Accelerometer. A program is run which prints a reading from the accelerometer in the horizontal position (approximately -1700) then the accelerometer is turned 90 degrees upwards and another reading is obtained (approximately -21320). It is important that the difference is -19620 (±50). If the difference is greater than ±50, a potentiometer must be adjusted. This procedure takes about 10 minutes if adjustment of the potentiometer is required, and about 2 minutes if no adjustment is needed. Calibration of the accelerometer is performed daily.

Calibration of DMI. A section of pavement must be measured accurately to 1300 feet (400 m) or less. A program is run which counts the number of pulses from the transducer as the RST travels the distance. At the end of the section the number of pulses is shown; the distance traveled is input and the computer calculates the number of pulses per meter and stores it. If a 400 m or less length is pre-measured, the procedure will take about 10 minutes. This is performed weekly.

Data Processing and Interpretation

Data is reduced in the field and outputs are printed using an on-board computer. The laser crack data is printed in six categories varying with regards to width and depth as explained in Figure 26. Macrotexture is also measured by lasers. The computer sorts the texture into various wave forms. Wave length between 2 mm and 10 mm are grouped as fine macrotexture and rough macrotexture group includes wavelengths between 10 mm and 80 mm. For both groups, a root mean square (RMS) is calculated which is a measure of amplitude. These values are distributed into ten ranges. The value in each range is a percentage of the length of the section where the RMS value was in that range.

A cross profile of the section based on the readings of eleven laser sensors can also be plotted for each section. Appropriate training and experience is required to extract meaningful results from the output.

Output

The output is printed in the field each 30 meters and at the end of the section. Finally, a summary output for the whole section is also printed using an on-board printer. Each output shows: inventory data, longitudinal roughness summary statistics, rut depths, section length information based on the three button entries, crack and texture data. The summary output also includes: subjective ratings based on entries from the eight toggle switches, mean profile based on all eleven sensors data, and deviation of each laser from the mean profile. Figure 26 explains the data printed on the outputs.

(1) Object: IMS Location Number

(2) Length: Actual length of section in meters

(3) Measured: Length of test section sampled, normally (2) & (3) are equal

(4) Speed: Average speed of RST over test section

(5)Quartr car: A ride quality index standard measured in mm per km.

RMSVA (MO): A secondary ride standard of root mean squared verticle acceleration

(6) Rut depth: Average rut depth over the test section of the deepest rut (sampling dist = 5 meters)

> 10 mm: Percentage of the test section with rut depth greater than 10mm

> 20 mm: Percentage of the test section with rut depth greater than 20mm

(7) Switches: Eight toggle switches for subjective input of environmental and inventory data

(8) No 1: Buttons for measuring lengths within a test section -- Value
No 2: is a percentage of the test section length during which the
No 3: button was depressed

(9) Cracking:

	Depth #1 (3mm-->6mm)				Depth #2 (6mm +)		MC* 6.0
	Width #1	W #2	W #3	W #4	W #2	W #3	
Laser #	3->6mm	6->12mm	12->25mm	25->50mm	6->12mm	12->50mm	*Both
Crack 1	60	26	14	0	5	4	
2	38	27	9	0	4	5	22
3	23	15	2	0	4	3	14
4	14	9	4	0	0	1	

Values in the "Both" category indicate numbers of cracks which both laser #1 and #2, or laser #3 and #4 measured at the same time.

MC is Macrotexture Compensation Factor

Note: All values indicate number of cracks per 100 meters

Figure 26. Explanation of raw data collected with the Laser RST.

(10) Macrotexture:

RMS values		---) category limits in mm									
meas. in mm	(----	<	0.2	0.3	0.4	0.6	0.9	1.3	2.0	3.0	5.0
	rms	0.2	0.3	0.4	0.6	0.9	1.3	2.0	3.0	5.0	>
macro 1											
rough	0.83	0	8%	28	25	19	7	8	3	0.0	0.0
fine	0.63	0	2	17	43	28	6	1	0	0.0	0.0
macro 4											
rough	0.54	2	48	14	14	10	6	1	0.0	0.0	0.0
fine	0.57	0	6	2	66	21	1	1	0.0	0.0	0.0

Explanation of terms:

RMS: Root Mean Square of the surface texture in mm

macro 1: Texture of left wheel path

4: Texture of right wheel path

rough: Surface texture with wavelength between 10mm and 80mm

fine: Surface texture with wavelength between 0mm and 10mm

(11) Profile: Average transverse profile of lane tested

Mean Profile: Average elevation of each laser above or below the line projected between lasers 1 and 11

Deviation: The standard deviation of each laser within the test section from the mean profile.

Figure 26. Explanation of raw data collected with the Laser RST (continued.)

Outputs are provided for each test run. In addition, a floppy disk was also provided to the research team. This disk contained the raw data in a dBASE III format for use on an IBM-PC or compatible computer.

Field Notes

Field tests were performed in the daytime on September 8 to 11, 1986. Calibrations of lasers, accelerometer and the DMI were checked in Austin on the first day. It took several trials on the first test section. On the other test sections, one run was adequate to collect data for the initial test. However, in some instances, the on-board computer gave a beep indicating that it did not record the data, because the RST was operated at a relatively high speed (above 50 mph or 80 kmph). This limitation was primarily due to the limited capacity of the on-board computer, according to the participating team. In general, speed varied between 25 and 50 mph (40 and 80 kmph).

Initial tests on CRCP sections did not show valid data for transverse cracks. The RST team contributed it to incorrect crack limits set in the software. Some of these tests were rerun on September 11, 1986 using the following crack limit settings in order to measure CRCP hairline cracks adequately.

	Original	CRCP
Depth 1	3mm - 6mm	1.5mm - 3mm
Depth 2	6mm and deeper	3mm and deeper
Width 1	3mm - 6mm	1mm - 3mm
Width 2	6mm - 12mm	3mm - 6mm
Width 3	12mm - 25mm	6mm - 12mm
Width 4	25mm - 50mm	12mm - 50mm

The accelerometer was mounted on the left (inside) wheelpath. On the first day, it was moved to the outside wheelpath. The roughness data was found to be of poor quality. The RST operators informed the research team this was due to insecure mounting of the accelerometer. The accelerometer was later mounted on its original position in the left wheelpath and several runs were repeated to obtain valid roughness data.

Future Development

Table 35 shows the response of the RST team for adaptability to the recommended list of distress categories. The following improvements and developments are expected during the next year (Ref 13).

- Installation of a Hewlett Packard Integral computer on-board the Laser RST.
- Acquisition of three new units (installed in North American vans) between now and the fall of 1988.
- Development and implementation of a video imaging system on the RST.
- Improved software for crack pattern recognition.

Table 35. Adaptability of the Laser RST method to survey the recommended list of distresses (Ref 13).

Distress	Units of Measure	Severity Rating	* Possible w/Video to Measure in Required Units	Measure in Units Req. w/ Present Laser RST
Flexible Pavements:				
Alligator/Fatigue Cracking	Sq.Ft.	Y	Y	N
Raveling	Sq.Ft.	Y	Y	N
Bleeding	Sq.Ft.	Y	Y	N
Block Cracking	Sq.Ft.	Y	Y	N
Longitudinal Cracking	Li.Ft.	Y	Y	N
Transverse Cracking	Li.Ft.	Y	Y	N
Potholes/Pothole Patching	No.	Y	Y	N
Reflection Cracking	Li.Ft.	Y	Y	N
Lane/Shoulder Drop-Off	M.S.L.	Y	Y	Y
Lane/Shoulder Separation	M.S.L.	Y	Y	Y
Rutting	Sq.Ft.	Y	Y	Y
Jointed Concrete Pavements:				
Blowups	No.	Y	Y	Y
Transverse Joint Spalling	#Joints	Y	Y	N
Longitudinal Joint Spalling	#Joints	Y	Y	N
Joint Load Transfer Associated Deterioration	#Joints	Y	Y	Y
Pumping and Water Bleeding	H.S.L.	Y	Y	Y
Longitudinal "D" Cracking	Li.Ft.	Y	Y	N
Transverse "D" Cracking	Li.Ft.	Y	Y	N
Longitudinal Cracking	Li.Ft.	Y	Y	N
Transverse Cracking	Li.Ft.	Y	Y	N
Lane/Shoulder Drop-Off	M.S.F.	Y	Y	Y
Lane/Shoulder Separation	M.S.F.	Y	Y	Y
Corner Breaks	No.	Y	Y	N
Reactive Aggregate	%Area	Y	Y	N
Joint Faulting	Mn.In.	Y	Y	N
Continuously Reinforced Concrete Pavements:				
Transverse Crack Spalling	Li.Ft.	Y	Y	N
Longitudinal Crack Spalling	Li.Ft.	Y	Y	N
Transverse "D" Cracking	Li.Ft.	Y	Y	N
Longitudinal "D" Cracking	Li.Ft.	Y	Y	N
Pumping	Hi.Se.	Y	Y	Y
Scaling, Map Cracking, Crazing	Sev.L.	Y	Y	Y
Longitudinal Cracking	Li.Ft.	Y	Y	N
Longitudinal Joint Spalling	Li.Ft.	Y	Y	N
Longitudinal Joint Faulting	#Areas	Y	Y	Y
Punchouts	No.	Y	Y	Y
Construction Joint Deterioration	No.	Y	Y	Y
Reactive Aggregate	%Area	Y	Y	N
Lane/Shoulder Drop-Off	M.S.F.	Y	Y	Y
Lane/Shoulder Separation	M.S.F.	Y	Y	Y

* Future development

APPENDIX B. FIELD TESTING LOCATIONS AND SAMPLE DATA

This appendix provides information pertaining to the distress survey field tests conducted July through September 1986. The following items are included:

1. County maps identifying distress survey test sections.
2. Location and description of distress survey test sections.
3. Layout of a typical test section.
4. Field testing details for high-speed vehicles.
5. Names and addresses of distress survey participants.
6. Sample field data.

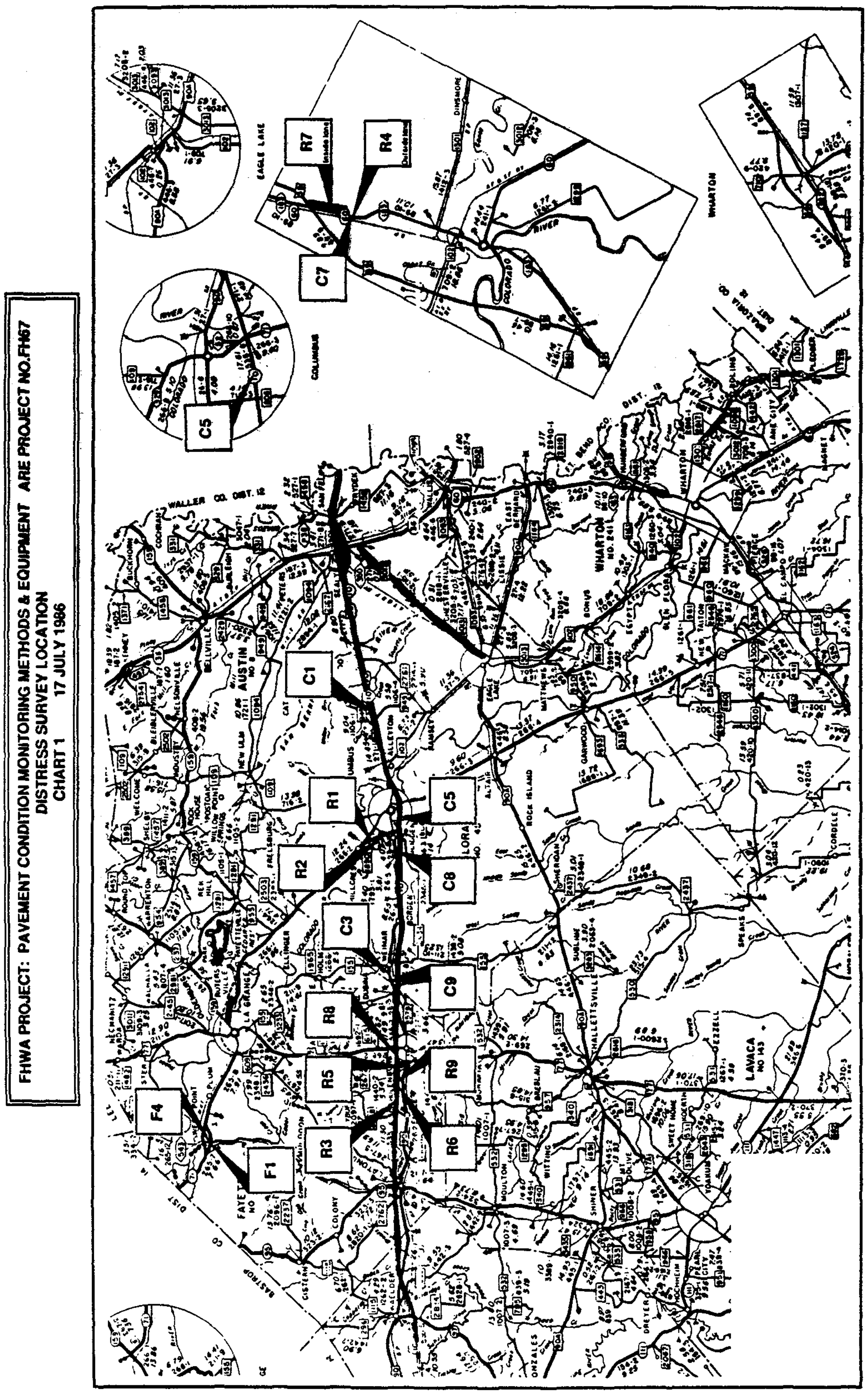


Figure 27. Location of distress survey test sections in Fayette, Colorado, and Wharton counties.

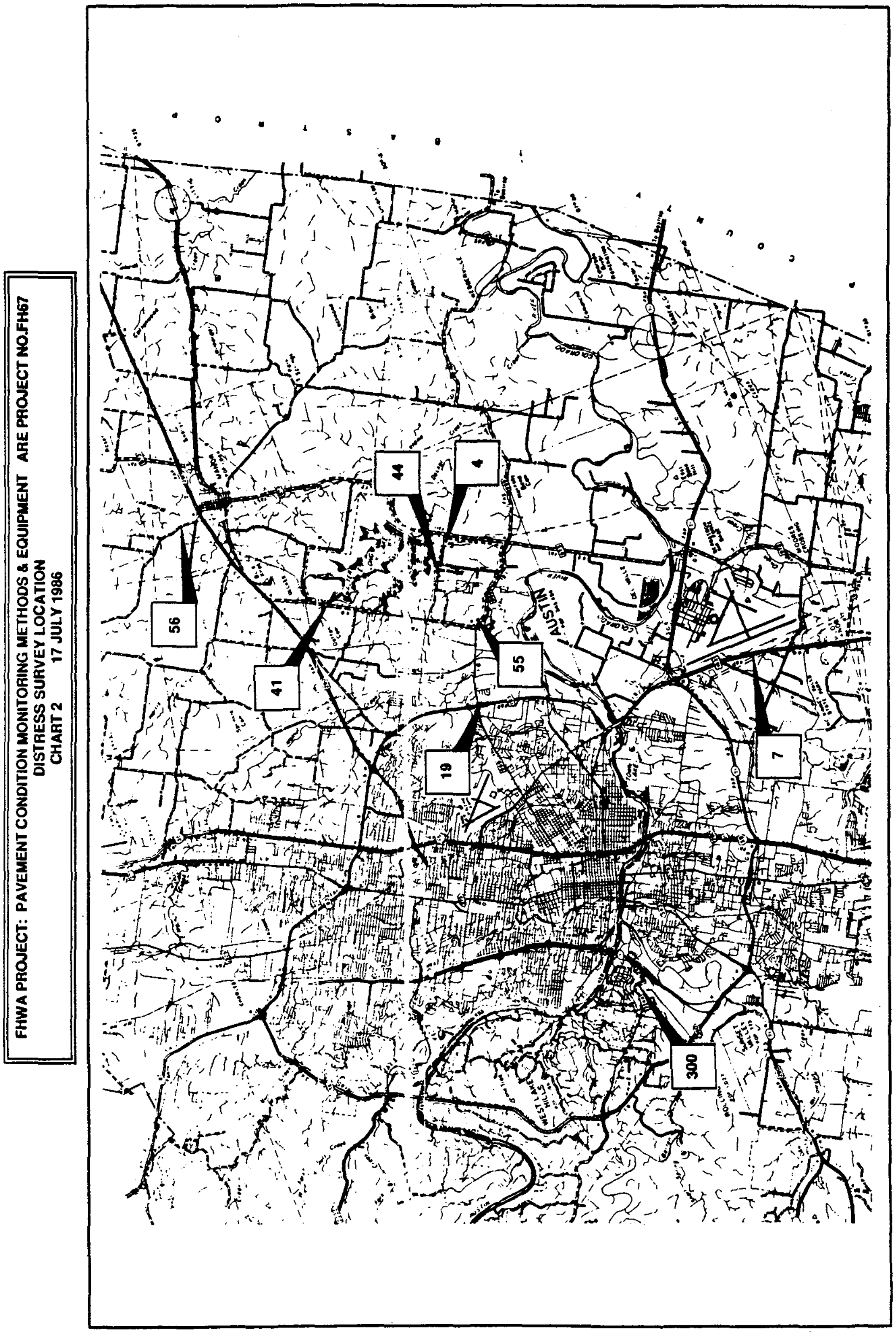


Figure 28. Location of distress survey test sections in Travis county.

Table 36. Description of distress survey sections.

A. Sections located in District 13 (Texas State Department of Highways and Public Transportation)

Highway	Direction	Location	Section	Pavement Type
SH 71	WB	West Point	F4	I
	EB	West Point	F1	I
SH 71 - Columbus bypass	SB	North of Colorado bridge	R1	II
	SB	South of Colorado bridge	R2	II
SH 60 - Wharton	NB	South of US 59	R4	III
			R7*	III
	SB	South of US 59	C7	IV
IH 10	WB	MP 705 east of Columbus	C1	V
IH 10	WB	MP 696 west of Columbus	C5	V
IH 10	WB	MP 693 east of Weimar	C8	V
US 90 (Exit #677 off IH 10)	EB	600 feet east of Exit #677 on IH 10	C9*	VII
	EB	2 miles east of creek at C9 end	C3	VII
IH 10	WB	After Schulenburg Exit	R8*	VI
		MP 673	R5	VI
		500 feet west of R5	R9	VI
		MP 672	R6	VI
		MP 670	R3	VI

*Repeat tests completed just after the initial run.

Note: All sections located in the outside lane except Sections F1 and R7 which were located in the inside lane.

Table 36. Description of distress survey sections (continued).

B. Sections located in District 14 (Texas State Department of Highways and Public Transportation).

Highway	Direction	Location	Section	Pavement Type
Greg Manor Rd.	NB	0.4 miles north of US 290	56*	I
FM 969	WB	Mile marker 6 east of FM 3177	55*	I
Decker Lake Rd.	EB	0.70 miles east of FM 3177	44*	I
FM 3177	SB	0.90 miles south of US 290	41*	I
US 183	NB	At FM 969 overpass	19	I
US 183	SB	1.5 miles north of Burleson Rd.	7	I
Decker Lake Rd.	EB	0.3 miles west of FM 973	4*	I
Bee Caves Rd.	WB	West of SB Loop 1 Frontage Rd.	300	I

*Repeat just tests completed after the initial run

Note: All sections located in the outside lane.

C. Blind Replicate Runs

Section designation:	#100	#101	#102	#103	#104	#105	#200	#201	#7
Replicate of sections:	F4	R2	C5	C9	C3	R8	41	44	7

Table 37. Typical pavement cross sections of the selected distress survey test sections.

Pavement Type	Pavement Cross Section
I	Asphalt concrete (variable thickness) Aggregate base (variable thickness)
II	10" continuously reinforced concrete 4" asphalt base 6" lime treated subgrade
III	10" jointed reinforced concrete pavement 4" asphalt base 6" lime treated subgrade
IV	1 to 2" asphalt concrete overlay 8" jointed reinforced concrete pavement 4" asphalt base 6" lime treated subgrade
V	3.5" asphalt overlay 8" continuously reinforced concrete pavement 6" cement stabilized base
VI	8" continuously reinforced concrete pavement 6" cement stabilized base
VII	1 to 2" asphalt overlay Thickened edge jointed reinforced concrete pavement (9" - 6" - 9")

Note: 1.0 inch = 25.4 mm

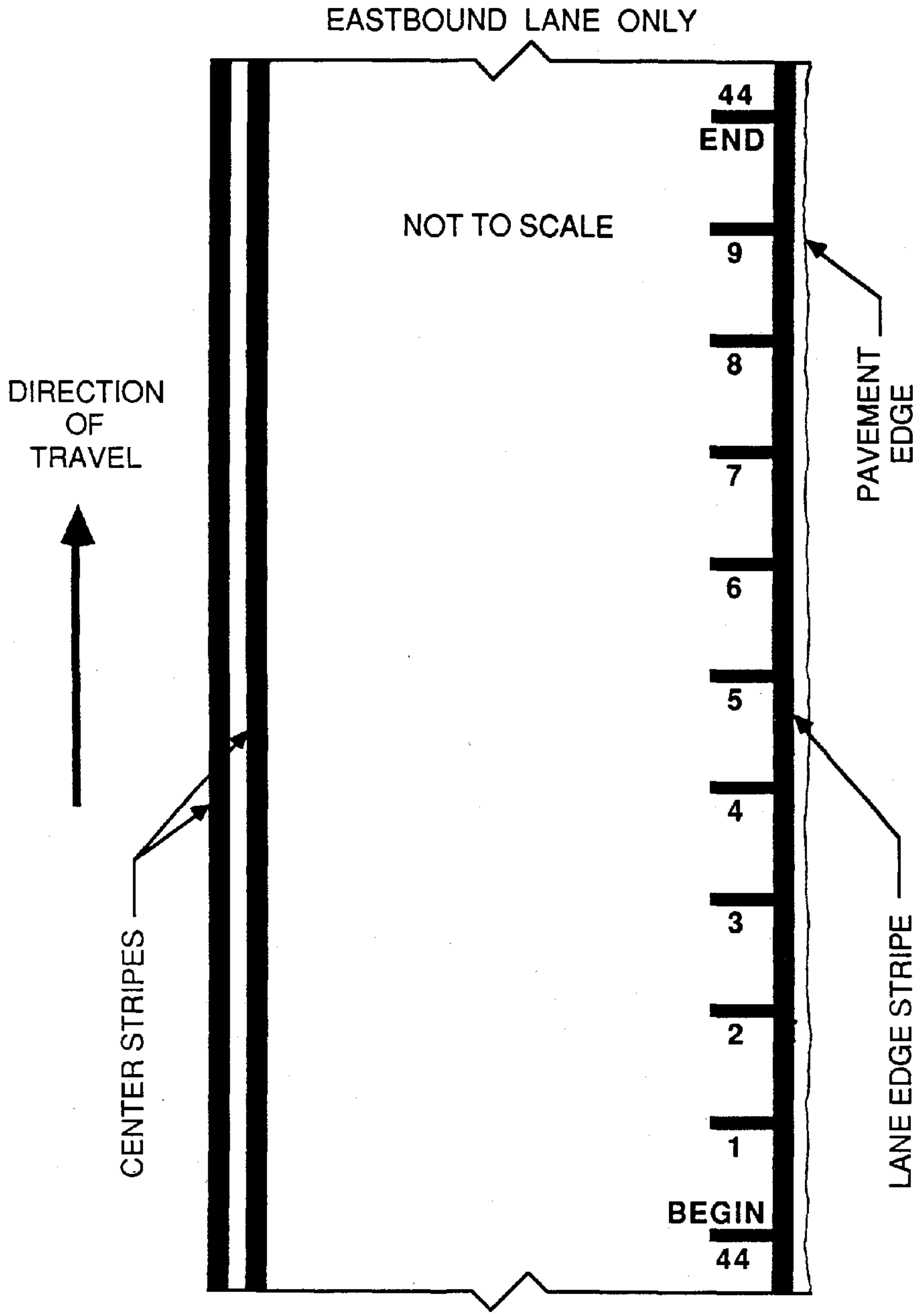


Figure 29. Layout of a typical 1000-foot (305 m) pavement test section.

Table 38. Field testing details for high-speed distress surveys.

Method	Test Dates	Pavement Sections	Remarks
GERPHO	7/17/86 (night)	F1,F4,R1,R2,C7,R4,R7, C1,C5,C8,C3,C9,R8,R5, R9,R6,R3 (Repeat runs on R7,C9,R8)	Clear, dry weather.
	7/18/86 (night)	56,44,41,4,55,19,7,300 (Repeat runs on 56,44, 41,4,55)	Clear, dry weather.
	7/20/86 (night)	101,102,104,103,105,100, 200,201,7	Clear, dry weather.
PASCO ROADRECON	7/21/86 (night)	300,56,44,41,4,55,19,7 (Repeat runs on 300,56, 44,41,4,55,19,7)	For surface distress & rut depths (ROADRECON -70 & -75), longitudinal roughness and laser survey (ROADRECON-77 and -85B).
	7/22/86 (night)	F1,F4,R1,R2,C7,R4,R7, C1,C5,C8,C3,C9,R8,R5, R9,R6,R3 (Repeat runs on R7,C9,R8)	For surface distress and laser survey (ROADRECON -70 and -85B).
	7/23/86 (night)	300,7,201,200,100,101, 102,104,103,105	For surface distress and laser survey (ROADRECON -70 & -85B). Clear & dry weather all three nights.
ARAN	9/2/86 (daytime)	Blake Manor Road, Austin Check calibration of the Distance Measuring Instrument (DMI)	DMI malfunction. DMI fixed on 9/3/86 by an HPI engineer from Canada.
	9/4/86 (daytime)	56,41,44,4,55,19,7,300, 102,101,104,103,105,100 (Repeat runs on 56,41, 44,4,55)	Rained in Columbus area. Tests only after clear weather. Distress, rut depth, roughness data, and video.

Table 38. Field testing details for high-speed distress surveys (continued).

Method	Test Dates	Pavement Sections	Remarks
	9/5/86 (daytime)	F4,F1,R1,R2,	Cloudy.
		C7,R4,R7,	Clear.
		C1,C5,C8,C3,C9,R8, R5,R9,R6,R3 (Repeat runs on R7,C9,R8)	Cloudy (Test was interrupted at C5,C9,R8,R5, & R9 due to rain & wet pavement conditions). Distress, rut depths, roughness data and video.
	9/6/86	-----	It was discovered that rut depth data collected on 9/5/86 was invalid (to be tested again on 9/8/86).
	9/7/86	201,200,7	Distress data on 7. Rut depths on 201,200.
	9/8/86 (daytime)	F4,F1,R1,R2,C7,R4,R7, C1,C5,C8,C3,C9,R8,R5, R9,R6,R3 (Repeat runs on R7,C9)	Rut depth measurements were made.
Laser RST	9/8/86 (daytime)	56,44,41,4,55,19,7,300 (Repeat runs on 44,41, 4,55)	Accelerometer moved to right wheelpath from left. Several runs made at the first section (56). Clear weather.
	9/9/86 (daytime)	F1,F4,R1,R2,C7,R4,R7,C1, C5 (Repeat run on R7)	Partly cloudy. Started raining at C5 (test delayed until the pavement dried).
		C8,C3,C9 (Repeat run on C9 at 50, 40 & 30 mph)	Sunny.
		R8,R5,R9,R6,R3,7 (Repeat run at R8)	Partly cloudy.
		200,201	Sunny.

Table 38. Field testing details for high-speed distress surveys (continued).

Method	Test Dates	Pavement Sections	Remarks
	9/10/86	56,200,201,4,55,17,7 100,101,102,104,103,105	Partly cloudy. Accelerometer moved to back left wheelpath as longitudinal roughness data of 9/8 and 9/9 were invalid. Operators claimed readings now were correct.
	9/11/86	R8,R5,R9,R6,R3 (These sections were retested to provide valid results by lasers for transverse cracks)	CRCP sections.

Table 39. Names and addresses of distress survey participants.

GERPHO

1. Mr. Michael P. Grippon

Vice President, MAP Inc.	MAP - Direction Commerciale
1825 Eye Street, Suite 400	23 Rue de La Sinne
Washington, D.C. 20006	68.100 - Mulhouse, France
Telephone: 202-429-2089	Telephone: (33) 89 5632 66
Telefax: 202-429-9574	Telefax: 88 1447 F

2. Mr. Robert J. Guillemin
   Manager, "Pavement Condition Evaluation Department"
   Laboratoire Central des Ponts et Chaussees (LCPC)
   Nantes, France

3. Mr. Jean Pierre Rodriguez
   Manager, "Group for Pavement Studies by Photography",
   Nancy, France.

4. Mr. Michael Mallot
   Interpretation Engineer, specialized in analysis and evaluation from photography, Autun, France.

5. Mr. Yvon Rodriguez
   Responsible for the maintenance of the GERPHO van, Nancy, France.

Table 39. Names and addresses of distress survey participants (continued).

PASCO ROADRECON

1. Mr. Shiges (George) Suzuki Corporate Planning International Operations PASCO Corporation	Mitsubishi International Corp. Project & Development Division 520 Madison Avenue New York, New York 10022 Telephone: 212-605-2324 Telex: WU 12482
2. Mr. Masanoi (Mac) Ohama Director for Corporate Planning, International Operations	PASCO Corporation No. 10-20, 7-Chome, Akasaka Minato-ku, Tokyo 107, Japan Telephone: 03-586-0671 Telex: 2468264 PASCO J Fax: 03-586-2385
3. Mr. Koroku Soma	PASCO Corporation, Japan
4. Mr. Yuji Taki	PASCO Corporation, Japan

ARAN

1. Mr. Frank Speers Manager, Marketing	Highway Products International Inc. R.R. No. 1, Paris, Ontario N3L3E1 Canada Telephone: 519-442-2261
2. Mr. Gary Marshall Operator, ARAN	FTS, Inc., Paris, Ontario, Canada Telephone: 519-442-2264

Table 39. Names and addresses of distress survey participants (continued).

3. Mr. Rick Mericlew Operator, ARAN	FTS, Inc., Paris, Ontario, Canada Telephone: 519-442-2264
4. Mr. Keith Martin Electrical Engineer	Highway Products International Inc.
5. Mr. Brian Kerr General Manager	Highway Products International Inc. Telephone: 519-442-2261
6. Mr. Eugene Chan Systems Analyst	Highway Products International Inc.
LASER RST	
1. Mr. Nathan C. Johnson Field Engineer	Infrastructure Management Serv. (IMS) 3350 Salt Creek Lane, Suite 117 Arlington Heights, Illinois 60005 Telephone: 312-506-1500
2. Mr. Ken Karl Operator, RST	IMS
3. Mr. Angel T. Floro Operator, RST	IMS
4. Mr. Robert L. Novak Head of Engineering	IMS

Table 39. Names and addresses of distress survey participants (continued).

MANUAL MAPPING, DETAILED VISUAL SURVEY METHODS

ARE Inc Staff	ARE, Inc 2600 Dellana Lane Austin, TX 78746 Telephone: 512-327-3520

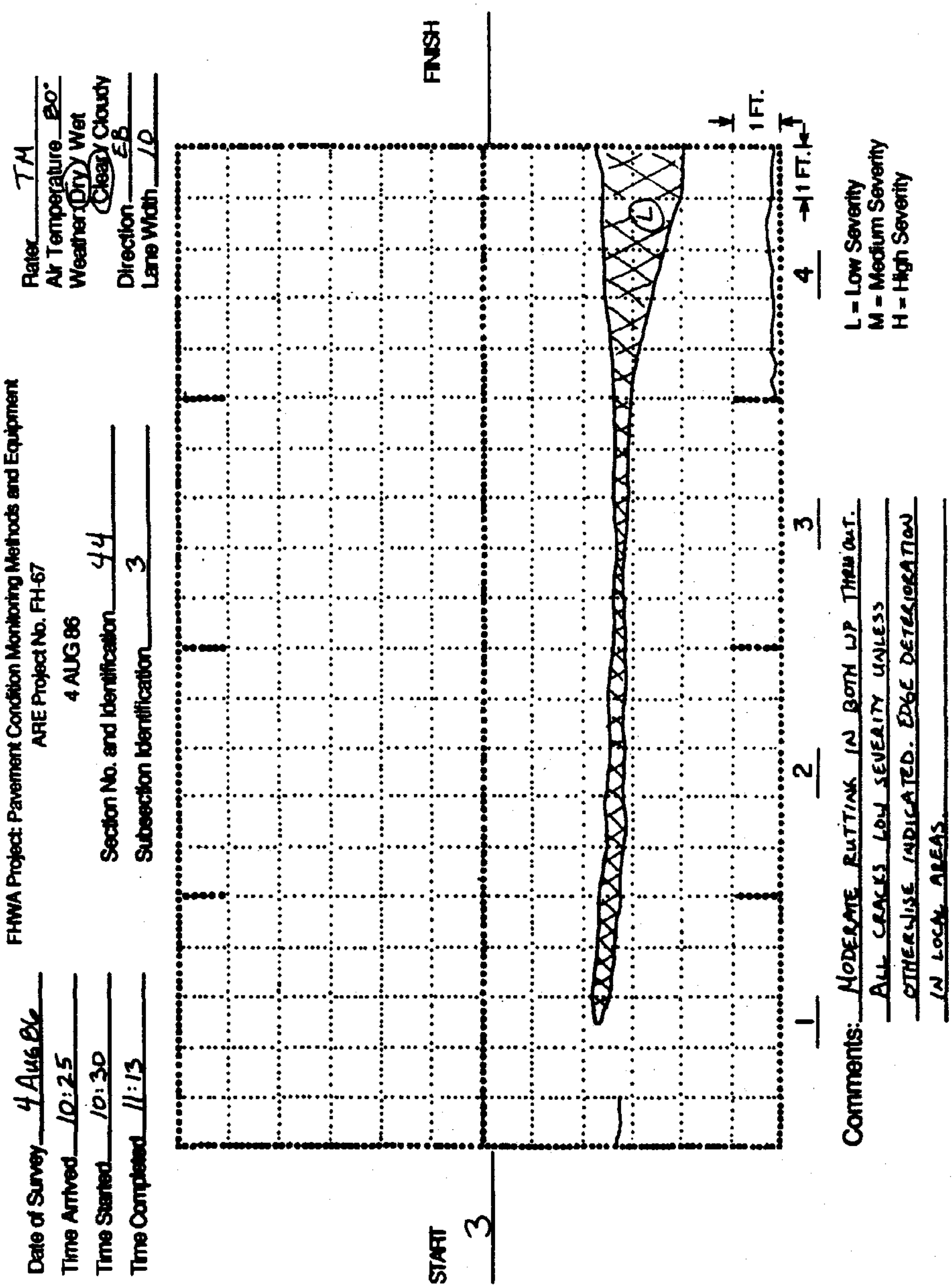


Figure 30. Sample field distress map, Section 44.

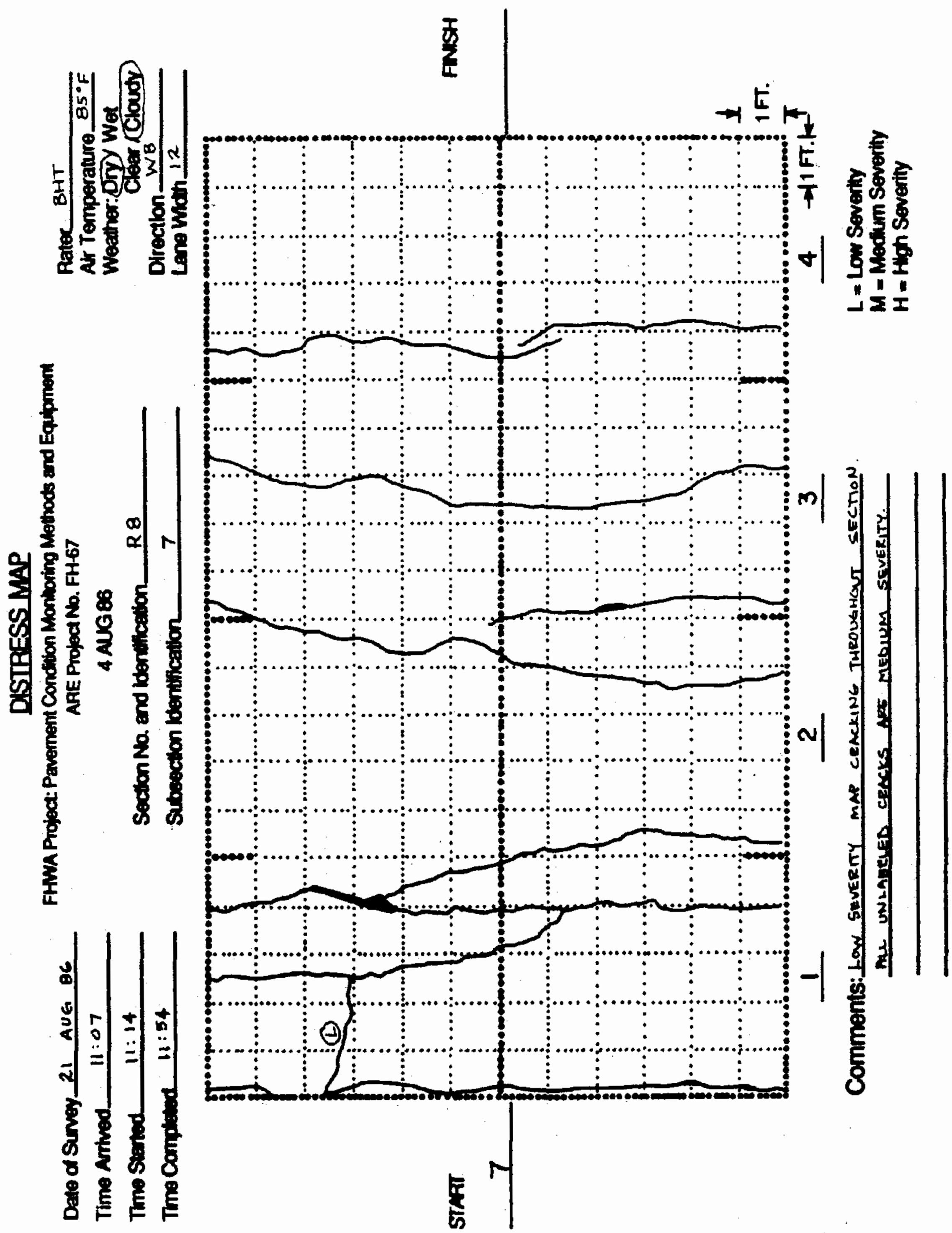


Figure 31. Sample field distress map, Section R8.

ASPHALT OR TAR SURFACED PAVEMENT
CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

BRANCH DECKER LAKE RD (44) **SECTION** 1

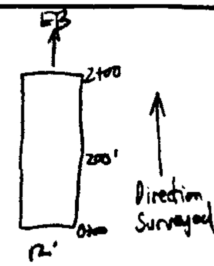
DATE 8/12/86 **SAMPLE UNIT** 1

SURVEYED BY LC/MC **AREA OF SAMPLE** 2400 ft²

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
4. Bumps and Sags
5. Corrugation
6. Depression
7. Edge Cracking
8. Jt. Reflection (PCC)
9. Lane/Shldr Drop Off
10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
13. Potholes
14. Railroad Crossings
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell

SKETCH



EXISTING DISTRESS TYPES

	1	2	7	15	16	
	200'x2' L	200'x3'L	175' M	30'x1' M	30ft² L	
		110'x2'L		10'x.5' L		
				5'x1'M		
				100'x.5'L		
TOTAL SEVER L	400	820		55	30	
TOTAL SEVER M			175	35		
TOTAL SEVER H						

PCI CALCULATION

DISTRESS TYPE	DENSITY	SEVERITY	DEDUCT VALUE
1	16.67	L	38
2	34.17	L	9
7	7.29	M	22
15	2.29	L	14
15	1.46	M	21
16	1.25	L	5
DEDUCT TOTAL			109
CORRECTED DEDUCT VALUE (CDV)			56

COMMENTS

PCI = 100-CDV = 44

RATING = FAIR

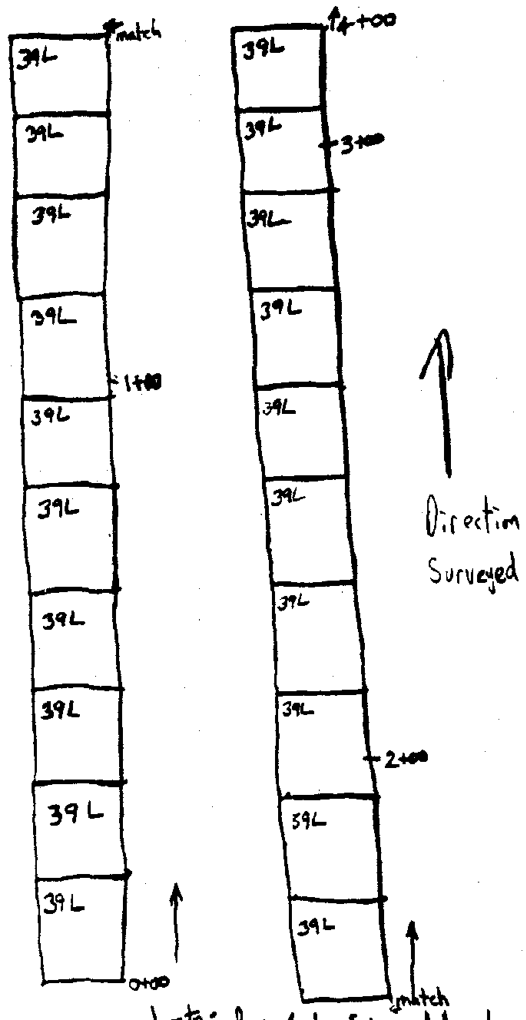
Figure 32. "PAVER" condition survey field data sheet, Section 44.

JOINTED CONCRETE PAVEMENT
CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

BRANCH SH60 (R7) SECTION 1

DATE 8/13/86 SAMPLE UNIT 1

SURVEYED BY LC/MC SLAB SIZE 20



Joint seal moderate: loss of bond to slab edge

Distress Types

21. Blow-up Buckling /Shattering
22. Corner Break
23. Divided Slab
24. Durability (D) Cracking
25. Faulting
26. Joint Seal Damage
27. Lane/Should. Drop Off
28. Linear Cracking
29. Patching, Large & Util. Cuts
30. Patching, Small
31. Polished Aggregate
32. Popouts
33. Pumping
34. Punchout
35. Railroad Crossing
36. Scaling/Map Cracking/Crazing
37. Shrinkage Cracks
38. Spalling Corner
39. Spalling, Joint

DIST. TYPE	SEV.	NO. SLABS	% SLABS	DEDUCT VALUE
39	L	20	100	12
26	M			4
DEDUCT TOTAL				16
CORRECTED DEDUCT VALUE (CDV)				16

PCI = 100 - CDV = 84

RATING = VERY GOOD

COMMENTS

Jt. 15' ~12' D.S.

Figure 33. "PAVER" condition survey field data sheet, Section R7.

R8

12 Sept 86

BHT/HLZ

SHEET 2F

UNIFORM SECTION FIELD DATA

-COPES-

Record No.	6.	1
State Code	__ __.	2-3
Proj. ID	__ __ __ __.	4-7
Unif. Sect.	__ __.	8-9
Time Sequence	__ __.	10-11

UNIFORM SECTION SURVEY

Uniform Section Location:

Start Pt. Mile Mark ____________

End Pt. Mile Mark ____________

Start Pt. Station No. ____________

End Pt. Station No. ____________

*U 1. Date Surveyed (day/month/year):

__ __/__ __/__ __ 12-17

*U 2. Foundation:

Majority at grade 1 18
Majority in cut 2
Majority in fill 3

*U 3. Depth of Typical Cut:

5 ft. or less 1 19
6-15 ft. 2
16-40 ft. 3
Greater than 40 ft. 4

U 4. Typical surface drainage in cut or at grade:

H* less than 2 ft. ..1 34
H between 2-5 ft. ...2
H greater than 5 ft..3
Tied Concrete Curb ..4

Other ____________5

*H=Distance from top of slab to bottom of side ditch or natural ground if no ditch.

U 5. Height of typical fill:

5 ft. or less 1 35
6-15 ft. 2
16-40 ft. 3
Greater than 40 ft. .4

36/BK

Record the number of occurances for each lane at each severity level.

	Distress Type/ Location	Left Lane Severity L	M	H			Right Lane Severity L	M	H	
U6L.	Depressions	__ __.	__ __.	__ __.	20-25	U6R.	01.	__ __.	__ __.	37-42
U7L.	Swells	__ __.	__ __.	__ __.	26-31	U7R.	01.	__ __.	__ __.	43-48
		Left Lane					Right Lane			
*U8L.	Mean Panel PSR	__.__			32-33	U8R.	2.6			49-50

51-78/BK
79-80/01

*Variables that were found to be highly important.

Figure 34. "COPES" condition survey field data sheet, Section R8.

SHEET 3F

SAMPLE UNIT FIELD DATA
-COPES-

Record No.	7	1
State Code		2-3
Proj. ID		4-7
Unif. Sect.		8-9
Time Sequence		10-11
Sample Unit Seq.		12

DISTRESS IDENTIFICATION

	Location	Left Lane					Right Lane			
	Severity	L	M	H			L	M	H	1-12/Dup.
	Distress type									
S 1L.	Blowup (No.)				13-18	S 1R.	0	0	0	11-18
S 2L.	Transverse Joint Spall (No. of Joints) (JPCP and JRCP only)				19-24	S 2R.				19-24
S 3L.	Longitudinal Joint Spalling (No. of Joints) (JPCP and JRCP only)				25-30	S 3R.				25-30
S 4L.	Reactive Aggregate Distress (% Area of Sample Unit)				31-39	S 4R.	0	0	0	31-39
S 5L.	Pumping (circle highest severity found)	0 1	2	3	40	S 5R.	0 1	(2)	3	40
S 6L.	Scaling, Map Cracking, or Crazing (circle highest severity found)	0 1	2	3	41	S 6R.	0 1	(2)	3	41
S 7L.	Longitudinal Joint Spalling (linear feet) (CRCP only)				42-50	S 7R.	0	0	0	42-50
S 8L.	Localized Distress (No. of Areas) (CRCP only)				51-56	S 8R.	0	0	0	51-56
S 9L	Edge Punchout (No.) (CRCP only)				57-62	S 9R.	Centerline → 55 + 26	00	00	57-62
S10L.	Construction Joint Deterioration (CRCP only)				63-68	S10R.	00	00	00	63-68

S11. Outer Shoulder Condition: 69

- Very good 1
- Good 2
- Fair 3
- Poor 4
- Very poor 5

S12. Foundation of Sample Unit: 70

- Fill Greater than 40 Ft. 1
- Fill 16-40 ft. 2
- Fill 6-15 ft. 3
- At Grade (5' fill to 5' cut) 4
- Cut 6-15 ft. 5
- Cut 16-40 ft. 6
- Cut Greater than 40' 7

S13. Expansion Joints (No.) 71-72

S14. Studded Tire Damage (Right Lane) 73

- Yes 1
- No 2

74-79/BK

79-80/01

S21. Transverse Joint Seal Damage (JRCP and JPCP) (Right Lane) 69

- Low 1
- Medium 2
- High 3

S22. Incompressibles in Transverse Joint (JRCP and JPCP) (Right Lane)

- Yes 1 70
- No 2

S23. Temporary Patching Present (Both Lanes)

- None or Very Minor 1 71
- Less than One-Half of the Joints 2
- Half or More of the Joints 3

73-79/BK

79-80/02

Figure 34. "COPES" condition survey field data sheet, Section R8 (continued).

SHEET 5F

SAMPLE UNIT FIELD DATA

-COPES-

Record No.	7	1-12/Dup.
State Code		
Proj. ID		
Unif. Sect.		
Time Sequence		
Sample Unit Seq.		

CRACKING AND FAULTING DATA
(Tabulated from Sheet 4F)

S31. Sample Unit Length (feet) 13-16

S32. Sample Unit Start Pt. - Mile Mark 17-21

S33. Sample Unit Start Pt. - Station No. 22-28

	Location	Left Lane					Right Lane			
	Severity	L	M	H			L	M	H	
	Distress Type									
S34L	Longitudinal "D" Cracking (linear ft.)				29-40	S34R	0	0	0	32-43
S35L	Transverse "D" Cracking (linear ft.)				41-49	S35R	0	0	0	44-52
S36L	Longitudinal Cracking (linear ft.)				50-61	S36R				53-64
S37L	Transverse Cracking (linear ft.)				62-73	S37R				65-76
S38L	Corner Breaks (No.) (low, medium and high)				74-75	S38R			0	77-78

76-78/BK

79-80/03

79-80/04

1-12/Dup

1-12/Dup

S39L	Cracking from Improper Joint Construction (linear ft.)(low, med, & high)		13-16	S39R		13-16
S40L	Transverse Joint Faulting (mean, inches) (JRCP/JPCP only)		17-19	S40R		17-19
S41L	No. of Longitudinal Joint Faulting Areas		20	S41R		20
	Lane/Shoulder Separation (Circle Mean Severity Found)			S42R	(1) 2 3	21

21-31/BK

22-78/BK

79-80/05

Figure 34. "COPES" condition survey field data sheet, Section R8 (continued).

SHEET 6F-R

SAMPLE UNIT FIELD DATA

-COPES-

Record No.	7	1-1./Dup
State Code		
Proj. ID		
Unif. Sect.		
Time Sequence		
Sample Unit Seq.		

PERMANENT PATCH DETERIORATION

(Reinforced Pavements)

Location	Left Lane					Right Lane			
Severity	L	M	H			L	M	H	

JRCP Permanent Patch at each Transverse Joint (slab replacement excluded)

		Left Lane					Right Lane			
	Total Asphalt Patch Area at a Joint ** (square feet)									
S61L.	Total Asphalt Patch (sq. feet)				13-24	S61R.				37-48
S62L.	No. of Joints Patched (asphalt)				25-30	S62R.				49-54
	Total PCC Patch Area at a Joint ** (square feet)									
S63L.	Total PCC Patch (sq. feet)				31-42	S63R.				55-66
S64L.	No. of Joints Patched (PCC)				43-48	S64R.				67-72

** Each cell represents one joint.

73-74/BK
74-80/07

JRCP Permanent Patch Not at a transverse joint, including slab replacement or CRCP Permanent Patch at any location.

		Left Lane					Right Lane			
	Asphalt Patch(es)* (square feet)						001			
S65L.	Total Asphalt Patch (sq. feet)				49-60	S65R.	001			13-24
S66L.	Asphalt Patch (No.)				61-66	S66R.	1			25-30
	PCC Patch(es)* (square feet)				67-78/BK 79-80/06 1-12/Dup		470 001 290 140 001			
S67L.	Total PCC Patch (sq. feet)				13-24	S67R.	1815	001		31-42
S68L.	PCC Patches (No.)				25-30	S68R.	10 8 6 (→5)	1		43-48

* Each cell represents one patch.

No. of Patches with Patch Adjacent Slab Deterioration (JRCP and CRCP)

		Left Lane			Right Lane	
S69L.	Corner Break		31-32	S69R.	00	49-50
S70L.	"D" Cracking		33-34	S70R.	00	51-52
S71L.	Spalling		35-36	S71R.	04	53-54

55-78/BK
79-80/08

Figure 34. "COPES" condition survey field data sheet, Section R8 (continued).

ARE PROJECT NUMBER 67 09-12-86

DATE	RATER	SECTION
12 Sep 86	BHT	R8

TRANSVERSE CRACKS 12'

SUBSECTION	LOW	MEDIUM	HIGH
0-1	27.5	12	0
1-2	18.5	11.5	0
2-3	26	9	0
3-4	14	16	0
4-5	14.5	16	0

LONGITUDINAL CRACKS 6'

SUBSECTION	LOW	MEDIUM	HIGH
0-1	6	0	0
1-2	0.5	0.5	0
2-3	1	0	0
3-4	0	0	0
4-5	0	0	0

Figure 35. Supplement to "COPES" condition survey field data sheet, Section R8.

```
PAGE(3)    44
SUBPG(2)      RPT
# LNS(1)   1 PUMT 0
LN WDTH(2)10 DIR  3

   GP|     LMS|
PTH  |EDGE 2  |BLD 2
UTL  |        |DRN 2
SHL3 |        |INT

  LMS|     LMS|
ALL1 |LNG 1   |RUL
BLK1 |RUT  2  |LLP 1
TRN2 |
```

Figure 36. Sample of hard copy produced in field by automated data logger, Section 44.

PAVEMENT CONDITION MONITORING METHODS AND EQUIPMENT
ARE INC. AUSTIN (TEXAS) - JULY 1986

GERPHO DATA OUTPUT — ASPHALT PAVEMENT
DATA COLLECTION — FRENCH METHOD

DATE: 18/07/1986
SECTION: 44 SEQ: 26 LANE: OUTSIDE

LENGTH SECTION: 305 METERS

GUIDE-MARKS		ALLIG-ATOR CRACKS	LONGITUDINAL CRACKS		OPEN JOINTS		TRANSVERSE CRACKS		HIGH SEVER POTH.	PUMP.	STRIP.	BLEE.	LOW SEVER POTH.	SEALED TRANS. CRACKS	LONG.CRACKS		PATCH.
GM	DIST GM	SQ M	I.W.P M	O.W.P M	LONG. M	TRAN.	SINGLE QTY	MULTIPLE QTY	QTY	QTY	M	M	SQ M	QTY	TOT.L M	S.L M	SQ M
0	0	2		11							12				11		
0	20		10	14			1			1	18	2			24		1
0	40			13							6	20			13		
0	60	2	4	11			2				12	20			15		
0	80	1	14	13			3				4	20			27		
0	100		20*	7			8				7	20			31		
0	120		20*	18						1	3				40		
0	140		15	15							2	20			30		
0	160		15	13*							5	20			40		
0	180	2	17*	18						1	8	20			34		
0	200		14*	3								15			25		
0	200	END DIST															
0	220										8						
0	240										5						
0	260											2					
0	280	6	8	6						1			2		14		1
0	300	3	1	4						1	4				5		

TYPICAL PAVEMENT TYPE

***
** A-I **
***

ASPHALT CONCRETE
AGREGATE BASE

Figure 37. GERPHO (French method) distress data output, Section 44.

PAVEMENT CONDITION MONITORING METHODS AND EQUIPMENT
ARE INC. AUSTIN (TEXAS) - JULY 1986

GERPHO OUTPUT - JOINTED PLAIN CONCRETE DATA COLLECTION - FRENCH METHOD

DATE: 17/07/1986
SECTION: R7 SEQ: 7 LANE : INS
LENGTH SECTION: 305 METERS

NUMBER SLABS REF.	N	L.J. P	TRANS CRACK. P	DIAGO CRACK. P	LONG. CRACK. P	SP P	CB P	PUMP	RECONSTRUCTION PATCH C	PATCH A	WIDTH C	WIDTH A	FULL C	FULL A	SCALING IN.WP DM2	IN.WP NU	OUT.WP DM2	T J	L J	SLC	IA	REP.
	1	P.C.C ZONE POSITION AT 0 METERS OF GM 000																				
	2					1																
	3					2																
	5					1																
	6					2																
	7					1																
	11	LOW SEVERITY POTHOLES.																				
	12					2																
	14					1																
	15					1																
	16					2																
	17					4																
	20	LOW SEVERITY POTHOLE.																				
	25					2																
	26					2																
	28	LOW SEVERITY POTHOLES.																				
	29					1																
	30					1																
	34					1																
	35					2																
	36					1																
	43					1																
	44					3																
	45					1																
	46					1																
	48					2																
	49					1																
	51			1																		
	53					1																
	59					1																
	61					3																
	62					2																
	62	LONG.JOINT LOW SEVERITY SPALLING																				
	62	LOW SEVERITY CRAZING.																				
		END GM 000 AT 305 METERS																				

TYPICAL PAVEMENT TYPE

******
** BD-III **
******

JOINTED REINFORCED CONCRETE (10'')
ASPHALT BASE (4'')

Figure 38. GERPHO (French method) distress data output, Section R7.

PAVEMENT CONDITION MONITORING METHODS AND EQUIPMENT
ARE INC. AUSTIN (TEXAS) - JULY 1986

GERPHO OUTPUT - CONTINUOUSLY CONCRETE DATA COLLECTION - FRENCH METHOD

DATE: 17/07/1986
SECTION: R8 SEQ: 16 LANE: OUT
LENGTH SECTION : 304 METERS

LENGTH	L.J.		TRANS CRACK.		DIAGO CRACK.		LONG. CRACK.		TRANS CR.SP		CB		PUMP	RECONSTRUCTION PATCH		WIDTH		FULL		SCALING IN.WP DN2 NU	OUT.WP DN2	T J	L J	SLC	IA	REP.
		P		P		P		P		P		P		C	A	C	A	C	A							
000			8													C										
000	PATCHING WIDTH = 40SQ.M.																									
020			23				2		10																	
040			19						7																	
060			12						6							C										
060	PATCHING WIDTH = 25 SQ.M.																									
080			17						10																	
100			14						11							C										
100	PATCHING WIDTH = 16 SQ.M.																									
120			18						7																	
140			15						7																	
160			19						12																	
180			19						10																	
200			19						11																	
220			20						9																	
240			12						2																	
240	TRANSVERSAL JOINT.																									
260			23				4		12																	
280			28				6									C										
280	PATCHING WIDTH = 16 SQ.M.																									
300			6				1		2																	

TYPICAL PAVEMENT TYPE
*****
** BC-VI **
*****

CONTINUOUSLY REINFORCED CONCRETE (8'')
STABILIZED BASE (6'')

Figure 39. GERPHO (French method) distress data output, Section R8.

SHEET 2	STATE CODE	:	TX
MONITORING DATA	PROJECT ID	:	44
LTM PROGRAM	DATE (MONTH/DAY)	:	0718
	YEAR	:	86

DISTRESS SURVEY FOR PAVEMENTS WIDTH A FLEXIBLE SURFACE

LANE NUMBER : 0 SUBSECTION NUMBER : 0

DISTRESS TYPE	SEVERITY LEVEL		
	LOW	MODERATE	HIGH
ALLIGATOR/FATIGUE CRACKING (SQUARE FEET)	75	0	0
RAVELING (SQUARE FEET)	355	0	0
BLEEDING (SQUARE FEET)			0
BLOCK CRACKING (SQUARE FEET)	0	0	0
LONGITUDINAL CRACKING (LINEAR FEET)	36	0	0
TRANSVERSE CRACKING (LINEAR FEET)	0	0	0
POTHOLES/POTHOLE PATCHING (NUMBER)	0	0	0
REFLECTION CRACKING (LINEAR FEET)	0	0	0
LANE/SHOULDER DROPOFF OR HEAVE-MEAN SEVERITY FOUND (1 FOR LOW. 2 FOR MODERATE. 3 FOR HIGH MEAN SEVERITY)			0
LANE/SHOULDER SEPARATION-MEAN SEVERITY FOUND (1 FOR LOW. 2 FOR MODERATE. 3 FOR HIGH MEAN SEVERITY)			0

Figure 40. GERPHO (LTM program) distress data output, Section 44.

SHEET 4	STATE CODE : TX
MONITORING DATA	PROJECT ID : R7
LTM PROGRAM	DATE (MONTH/DAY) : 0717
	YEAR : 86

DISTRESS SURVEY FOR PAVEMENTS WIDTH

JOINTED RIGID SURFACES

LANE NUMBER : I   SUBSECTION NUMBER : 0

DISTRESS TYPE	SEVERITY LEVEL		
	LOW	MODERATE	HIGH
BLOWUPS (NUMBER)	0	0	0
TRANSVERSE JOINT SPALLING (NO. OF JOINTS)	4	0	0
LONGITUDINAL JOINT SPALLING (NO. OF JOINTS)	0	0	0
JOINT LOAD TRANSFER SYSTEM ASSOCIATED DETERIORATION (NO. OF JOINTS)	0	0	0
PUMPING AND WATER BLEEDING HIGHEST SEVERITY FOUND (1 FOR LOW. 2 FOR MODERATE. 3 FOR HIGH SEVERITY)			0
LONGITUDINAL D CRACKING (LINEAR FEET)	0	0	0
TRANSVERSE D CRACKING (LINEAR FEET)	0	0	0
LONGITUDINAL CRACKING (LINEAR FEET)	0	0	0
TRANSVERSE CRACKING (LINEAR FEET)	0	0	0
LANE/SHOULDER DROPOFF OR HEAVE. MEAN SEVERITY FOUND (1 FOR LOW. 2 FOR MODERATE. 3 FOR HIGH SEVERITY)			0
LANE/SHOULDER SEPARATION. MEAN SEVERITY FOUND (1 FOR LOW. 2 FOR MODERATE. 3 FOR HIGH SEVERITY)			0
CORNERS BREAKS (NUMBER ALL SEVERITIES)			0
REACTIVE AGGREGATE (% OF AREA)			0

Figure 41. GERPHO (LTM program) distress data output, Section R7.

```
SHEET 6                  STATE CODE          : TX
MONITORING DATA          PROJECT ID          :   R8
LTM PROGRAM              DATE (MONTH/DAY)    : 0717
                         YEAR                : 86
```

DISTRESS SURVEY FOR PAVEMENTS WIDTH

CONTINUOUSLY REINFORCED RIGID SURFACES

LANE NUMBER : 0 SUBSECTION NUMBER : 0

DISTRESS TYPE	SEVERITY LEVEL LOW	MODERATE	HIGH
TRANSVERSE CRACK SPALLING (LINEAR FEET)	45	0	0
LONGITUDINAL CRACK SPALLING (LINEAR FEET)	0	0	0
TRANSVERSE D CRACKING (LINEAR FEET)	0	0	0
LONGITUDINAL D CRACKING (LINEAR FEET)	0	0	0
PUMPING (HIGHEST SEVERITY) (1 FOR LOW, 2 FOR MODERATE, 3 FOR HIGH SEVERITY)			0
SCALING, MAP CRACKING, CRAZING (1 FOR LOW, 2 FOR MODERATE, 3 FOR HIGH SEVERITY)			1
LONGITUDINAL CRACKING (LINEAR FEET)	0	0	0
LONGITUDINAL JOINT SPALLING (LINEAR FEET)	0	0	0
LONGITUDINAL JOINT FAULTING (NUMBER OF AREAS)			0
PUNCHOUTS (NUMBER)	0	0	0
CONSTRUCTION JOINT DETERIORATION (NUMBER)	0	0	0
REACTIVE AGREGATE (% OF AREA)			0
LANE/SHOULDER DROPOFF (MEAN SEVERITY) (1 FOR LOW, 2 FOR MODERATE, 3 FOR HIGH SEVERITY)			0
LANE/SHOULDER SEPARATION (MEAN SEVERITY) (1 FOR LOW, 2 FOR MODERATE, 3 FOR HIGH SEVERITY)			0

Figure 42. GERPHO (LTM program) distress data output, Section R8.

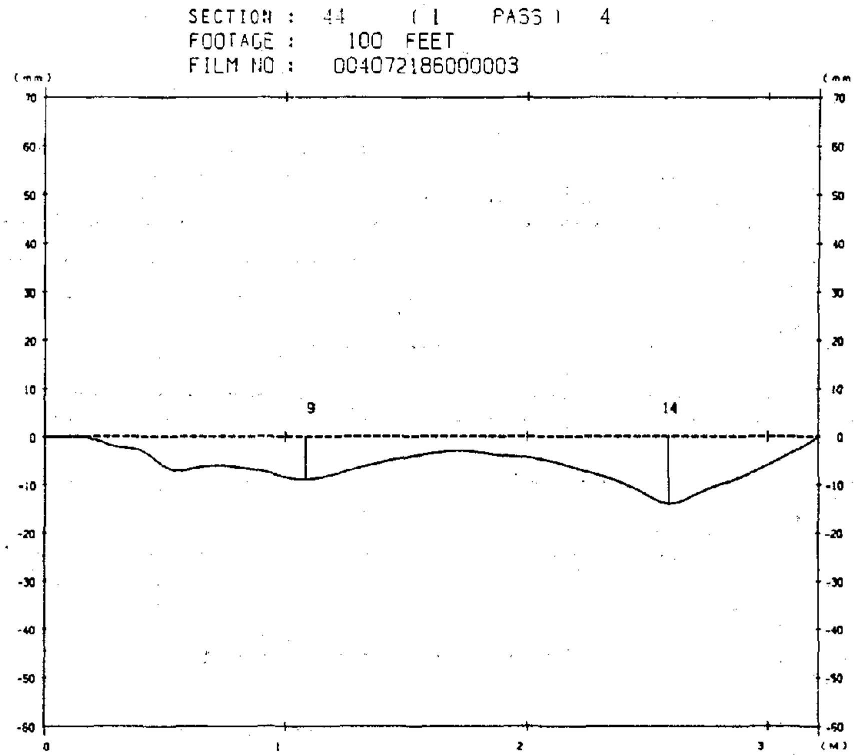
TEXAS／ARE

路面性状データ一覧表

距離程(km) 自	距離程(km) 至	クレーキ	構造物 1	構造物 2	区間延長(m)	測定値 調査年度	測定値 路面種別	ひびわれ率(度)(%, cm/m²) クラック	ひびわれ率 パッチング	ひびわれ率 計	わだち掘れ量(mm) 最大値	わだち掘れ量 平均値	縦断凹凸量 σ (mm)	MCI 最小	MCI式	予測値 路面種別	ひびわれ率(度)(%, cm/m²)	わだち掘れ量(mm) 最大値	わだち掘れ量 平均値	縦断凹凸量 σ (mm)	MCI 最小	MCI式	舗設年度	最新補修 年度	最新補修 工法	経年数	地域区分(1)	地域区分(2)	道路区分	CBR (%)	TA (cm)	摘要
1.000	1.305				305	S61	AS	2.0	0.0	2.0	37	9	3.06	6.3	1																	I
2.000	2.305				305	S61	AS	72.6	0.5	73.2	72	46	4.90	0.0	1																	I
3.000	3.305				305	S61	AS	0.0	0.0	0.0	37	13	2.11	6.8	4																	I
4.000	4.305				305	S61	AS	5.4	0.1	5.5	49	20	3.64	4.6	1																	I
5.000	5.305				305	S61	AS	6.2	0.0	6.2	34	18	4.17	4.6	1																	I
6.000	6.305				305	S61	AS	0.9	22.9	23.8	18	10	2.40	4.2	1																	I
7.000	7.305				305	S61	AS	0.0	0.0	0.0	15	12	1.38	7.0	4																	I
8.000	8.305				305	S61	AS	2.2	0.0	2.2	5	4	1.54	6.8	1																	I
9.000	9.305				305	S61	AS	1.1	0.0	1.1				7.7	3																	I
10.000	10.305				305	S61	AS	6.6	0.0	6.6				6.1	3																	I
11.000	11.305				305	S61	CO	52.0	0.0	52.0				1.1	3																	II
12.000	12.305				305	S61	CO	32.1	0.0	32.1				2.4	3																	II
13.000	13.305				305	S61	AS	10.6	0.0	10.6				5.5	3																	IV
14.000	14.305				305	S61	CO	0.3	0.0	0.3				8.5	3																	III
15.000	15.305				305	S61	CO	0.6	0.0	0.6				8.1	3																	III
16.000	16.305				305	S61	AS	0.2	0.0	0.2				8.5	3																	V
17.000	17.305				305	S61	AS	36.8	0.2	37.0				3.4	3																	V
18.000	18.305				305	S61	AS	4.5	0.2	4.7				6.5	3																	V
19.000	19.305				305	S61	AS	21.3	0.0	21.3				4.4	3																	VII
20.000	20.305				305	S61	AS	54.3	0.5	54.8				2.6	3																	VII

PASCO USA INC.

Figure 43. PASCO's road surface condition data table, section summary.



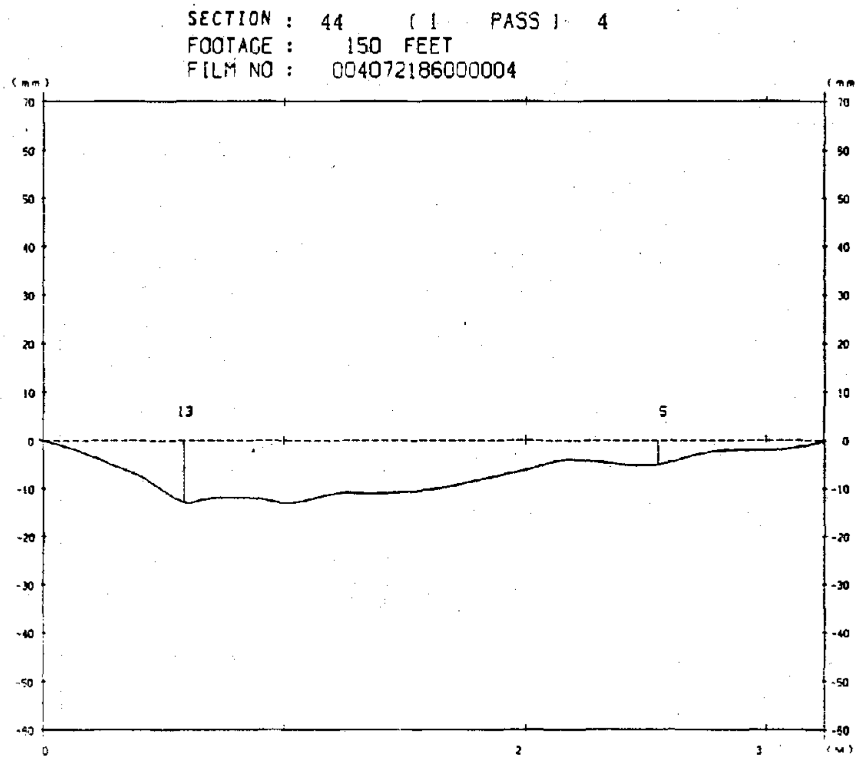


Figure 44. PASCO'S ROADRECON-75 output, cross profile of Section 44.

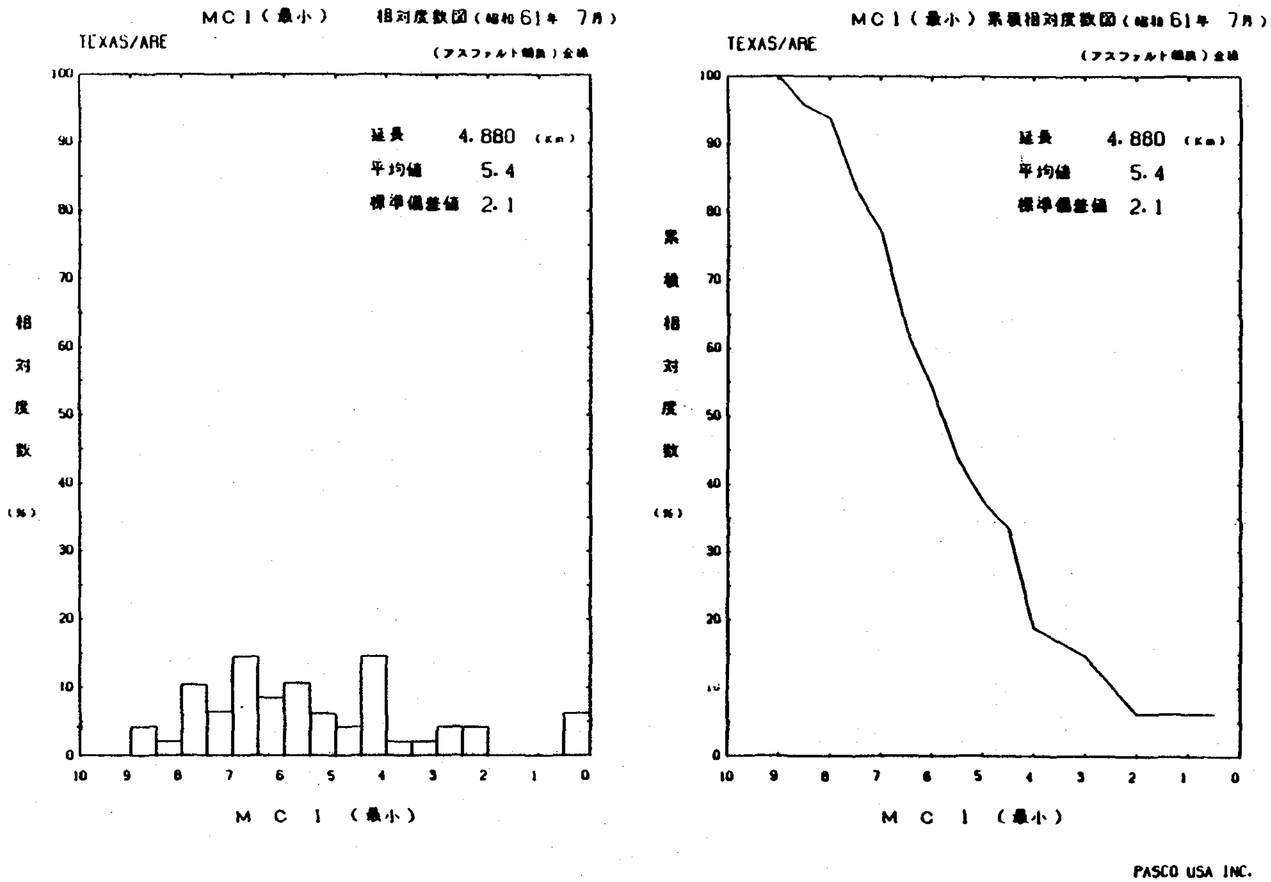


Figure 45. Relative and cumulative frequency diagram for PASCO'S maintenance control indices (MCI).

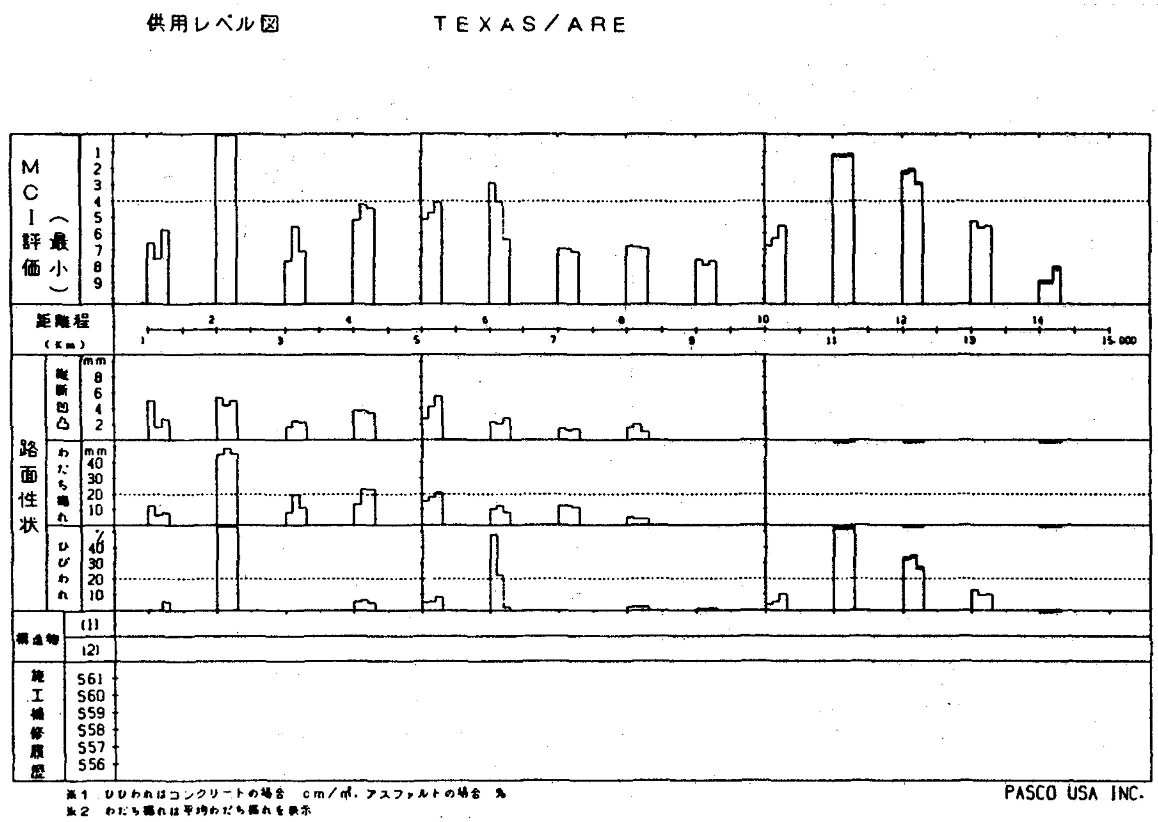


Figure 46. PASCO's pavement performance chart (a diagram used to select sections to be repaired).

Laser Road Surface Tester
hiway Program
Sep. 8, 1986 18:10:54
Ver 03.86c

section 44 trial 1

Object

Object	5
Length	305 m
Measured	305 m
Speed	64 km/h
Qcar IRI	15.5 mm/m
MO	11.7 miles/1000
Rut Dpth	11.0 mm
>10.0mm	45 %
>20.0mm	12 %
Button 1	0 %
Button 2	0 %
Button 3	0 %
Switches	2 3 3 1 1 2 2 2

Mean Prf	0.0	8.8	12.5	18.1	18.1	21.4	18.2	17.3	6.7	-3.3	0.0
Dev Prf	0.0	5.1	5.0	5.4	5.9	6.5	6.7	6.9	7.6	7.4	0.0

	3.0				6.0		
	3.0	6.0	12.0	25.0	6.0	12.0	
	6.0	12.0	25.0	50.0	12.0	25.0	100
Crack 1	0	0	0	0	0	0	
2	0	0	0	0	0	0	0
Crack 3	0	0	0	0	0	0	
4	2	0	0	0	0	0	0

			0.2	0.3	0.4	0.6	0.9	1.3	2.0	3.0	5.0
	RMS	0.2	0.3	0.4	0.6	0.9	1.3	2.0	3.0	5.0	
Macro 1											
Rough	0.41	13	19	23	36	6	0	0	0	0	0
Fine	0.78	4	10	8	17	36	16	4	0	0	0
Macro 2											
Rough	0.43	10	16	30	33	6	1	0	0	0	0
Fine	0.88	6	1	2	7	41	31	6	0	0	0

Figure 47. IMS' Laser RST field distress data output, Section 44.

SURFACE DISTRESS INDEX   Sept 09 1986
DETAILED INVENTORY REPORT   Page 1

OPER   Control Section : 00

ROUTE : S044-A: Inner Eastbound

STATION	RIP/ SHOV	RAV/ STRK	FLUS H/BL	DIST ORTN	EX C ROWN	EDGE CRAK	ALLI GATR	POT HOLE	MAP CRAK	LONG CRAK	TRAN CRAK	SDI
0.020	0-0	0-0	1-3	0-0	0-0	0-0	0-0	0-0	0-0	0-4	0-0	4.4
0.040	0-0	0-0	1-3	0-0	0-0	0-0	0-0	0-0	0-0	0-4	0-0	4.4
0.060	0-0	0-0	1-3	1-3	0-0	0-0	0-2	0-0	0-0	0-3	0-0	4.3
0.080	0-0	0-0	1-4	1-3	0-0	0-4	0-2	0-0	0-0	0-3	0-0	3.5
0.100	0-0	0-0	1-5	1-3	0-0	0-4	0-2	0-0	0-0	0-3	0-0	3.5
0.120	0-0	0-0	1-5	1-3	0-0	0-4	0-2	0-0	0-0	0-3	0-0	3.5
0.140	0-0	0-0	1-5	1-3	0-0	0-0	0-2	0-0	0-0	0-3	0-0	4.2
0.160	0-0	0-0	0-0	1-3	0-0	0-0	0-0	0-0	0-0	0-0	0-0	4.8
0.180	0-0	0-0	0-0	1-3	0-0	0-0	0-2	0-0	0-0	0-0	0-0	4.6

Survey Date : Sept 04 1986   Weather : Sunny & Clear
No. Of Tests : 9 Interval :0.020 mi Length Of Lane : 0.180 mi

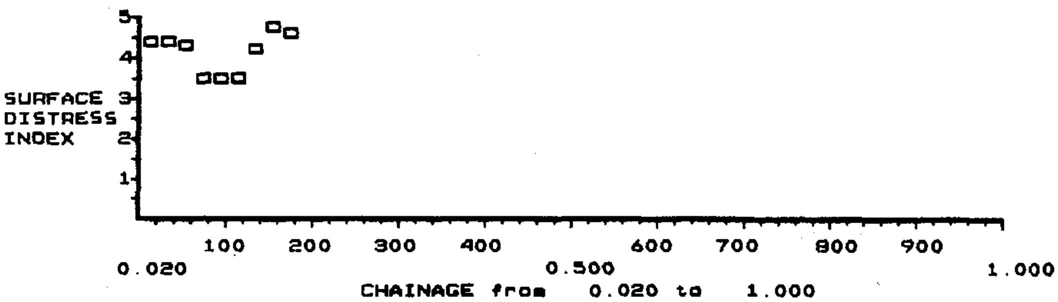
Figure 48. HPI'S ARAN distress survey data output, Section 44.

SURFACE DISTRESS INDEX
SECTION SUMMARY REPORT

Sept 09 1986
Page 2

OPER Control Section : 00

ROUTE : S044-A : Inner Eastbound



SECTION SUMMARY

Mean SDI : 4.1
Std.Deviation : 0.5

Minimum SDI : 4 At 0.080
Maximum SDI : 5 At 0.160

Survey Date : Sept 04 1986
Weather : Sunny & Clear
No. Of Tests : 9 Interval :0.020 mi Length Of Lane : 0.180 mi

Figure 48. HPI'S ARAN distress survey data output, Section 44 (continued).

RUT DEPTH ANALYSIS
DETAILED INVENTORY REPORT

Sept 09 1986
Page 1

OPER Control Section : 00

ROUTE : 5044-A: Inner Eastbound

CHAINAGE		LEFT RUT				RIGHT RUT			
			Average	Percent Over			Average	Percent Over	
Start	End	No.	Depth	0.50in	0.25in	No.	Depth	0.50in	0.25in
0.020	0.020	1	0.63 in	100.0%	100.0%	1	0.89 in	100.0%	100.0%
0.020	0.040	1	0.21 in	0.0%	0.0%	1	1.16 in	100.0%	100.0%
0.040	0.060	1	0.00 in	0.0%	0.0%	1	0.29 in	0.0%	100.0%
0.060	0.080	1	0.24 in	0.0%	0.0%	1	0.37 in	0.0%	100.0%
0.080	0.100	1	0.00 in	0.0%	0.0%	1	0.98 in	0.0%	100.0%
0.100	0.120	1	0.00 in	0.0%	0.0%	1	0.70 in	100.0%	100.0%
0.120	0.140	1	0.39 in	0.0%	100.0%	1	0.37 in	0.0%	100.0%
0.140	0.160	1	0.49 in	0.0%	100.0%	1	0.32 in	0.0%	100.0%
0.160	0.180	1	0.00 in	0.0%	0.0%	1	1.36 in	100.0%	100.0%
	Mean :		0.22 in				0.65 in		
	Std. Dev. :		0.24 in				0.40 in		

Survey Date : Sept 04 1986 Weather : Sunny & Clear
No. Of Tests : 9 Interval :0.020mi Length Of Lane : 0.180mi

Figure 48. HPI'S ARAN distress survey data output, Section 44 (continued).

PRESENT SERVICABILITY INDEX DETAILED INVENTORY REPORT — Aug. 04 1986, Page 1

OPER — Control Section : 00

ROUTE : S044-C: Inner Eastbound

Station	Mean Abs Slope	Measured Roughness	PSI	Event Chainage	Remark
0.020	4.66	420	3.9		
0.040	6.89	551	3.2		
0.060	9.74	521	3.4		
0.080	7.90	607	3.0		
0.100	5.88	522	3.4		
0.120	8.18	655	2.7		
0.140	9.13	838	1.8		
0.160	10.75	553	3.2		
0.180	10.78	419	3.9		
		--- 565.2	--- 3.2		

	Mean Abs Slope	Measured Roughness	PSI
Mean :	8.21	565.2	3.2
SDV :	2.12	127.8	0.6
Min PSI :			1.8
Max PSI :			3.9

Survey Date : Sept 04 1986 — Weather : Sunny & Clear

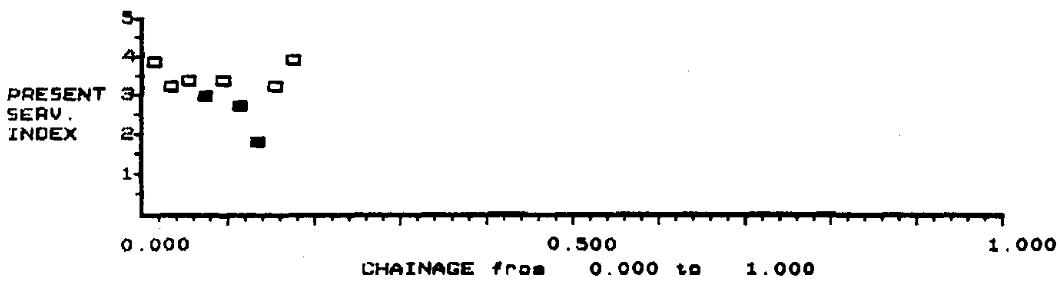
No. Of Tests : 9 Interval :0.020 mi — Length Of Lane : 0.180 mi

Figure 48. HPI'S ARAN distress survey data output, Section 44 (continued).

PRESENT SERVICABILITY INDEX Aug. 04 1986
SECTION SUMMARY REPORT Page 2

OPER Control Section : 00

ROUTE : S044-C: Inner Eastbound



SECTION SUMMARY

Mean PSI : 3.2 Minimum PSI : 1.8 At 0.140
Std. Deviation : 0.6 Maximum PSI : 3.9 At 0.180

Survey Date : Sept 04 1986 Weather : Sunny & Clear
No. Of Tests : 9 Interval :0.020 mi Length Of Lane : 0.180 mi

Figure 48. HPI'S ARAN distress survey data output, Section 44 (continued).

SURFACE DISTRESS INDEX
SECTION SUMMARY REPORT

Sept 09 1986
Page 7

OPER   Control Section : 00

ROUTE : IOR7-C: Inner Northbound

STATION	SCAL /RAV	POLI SHNG	AGG LOSS	SETT LEMT	EDGE CRES	SPAL LING	POT HOLE	CORN ER-D	LONG CRAK	TRAN CRAK	SEAL LOSS	SDI
0.020	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	5.0
0.040	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	5.0
0.060	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	5.0
0.080	0-0	0-0	0-0	0-0	0-0	0-0	1-1	0-0	0-0	0-0	0-0	4.8
0.100	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	5.0
0.120	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-2	4.9
0.140	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	5.0
0.160	0-0	0-0	0-3	0-0	0-0	0-0	0-0	0-0	0-0	0-0	0-0	4.9
0.180	0-0	0-0	0-3	0-0	0-0	0-0	0-2	0-0	0-0	0-0	0-0	4.8

Survey Date : Sept 05 1986   Weather : Sunny & Clear
No. Of Tests : 9 Interval :0.020 mi Length Of Lane : 0.180 mi

Figure 49. HPI'S ARAN distress survey data output, Section R7.

APPENDIX C. DISCUSSION OF DISTRESS DATA REPORTED ON THE PAVEMENT TEST SECTIONS

This appendix presents a detailed discussion and comparison of the distress data reported to be found by the selected methods and devices on each of the pavement test sections.

FLEXIBLE PAVEMENT TEST SECTIONS

Tables 15, 16, 17, 18, and 19 present a summary of several distresses reported to be found on the flexible test sections by the various survey methods and devices. These distresses are: alligator cracking, longitudinal cracking, transverse cracking, potholes/patching, and rutting. A section-by-section discussion and comparison of these reported distresses follows.

Section F1

Section F1 was a flexible pavement section considered to be in good condition. It was located on the inside lane of eastbound Highway 71, a heavily trafficked, divided, four-lane state highway.

Alligator cracking was reported to be low in severity and extent by all three visual survey methods (i.e., mapping, manual, and data logger). The manual visual survey however, showed significantly less alligator cracking than the other two methods. GERPHO, ARAN, and the Laser RST reported no alligator cracking. PASCO reported a crack ratio of one percent. This crack ratio included all types of cracking as well as patching.

In reporting longitudinal cracks, all three methods of visual survey rating agreed that only low severity longitudinal cracking existed. The data logger reported significantly more in extent, however, the data logger recorded only 1000-foot (305 m) equivalent full-length cracks. The Laser RST did not note any longitudinal cracks. GERPHO and ARAN reported a low amount of cracking.

Table 15. Comparison of reported alligator cracking for flexible pavement sections.

SECTION	DISTRESS *	MAPPING (Square Feet)	DETAILED VISUAL SURVEY Manual (Square Feet)	DETAILED VISUAL SURVEY Automated Data Logger (Percent of Area)	GERPHO (Square Feet)	PASCO** (Crack Ratio %)	ARAN (Percent of Area)	LASER RST (Percent of Area)
F1	Severity	Low	Low	Low	0	--	0	--
	Extent	110	7	1 - 10% (120 - 1200)	0	1.1	0	0
7 (Initial)	Severity	Low	Low	Low	Low	--	0	--
	Extent	60	110	1 - 10% (120 - 1200)	21	2.2	0	0
7 (Replicate)	Severity	--	--	Low	--	--	Low	--
	Extent	--	--	1 - 10% (120 - 1200)	--	2.1	10% (1200)	0
19	Severity	0	0	0	Low	--	0	--
	Extent	0	0	0	168	0.0	0	0
F4	Severity	Low	Low	Low	Low	--	Low, Mod	--
	Extent	1660	339	11 - 20% (1320 - 2400)	288	6.6	10% (1200)	0
100 (Replicate of F4)	Severity	--	--	Low	Low	--	Low, Mod	--
	Extent	--	--	11 - 20% (1320 - 2400)	149	6.5	10% (1200)	0
41 (Initial)	Severity	0	Low	Low	Low	--	0	--
	Extent	0	612	1 - 10% (100 - 1000)	1557	0.0	0	0
41 (Repeat)	Severity	--	--	--	--	--	0	--
	Extent	--	--	--	--	0.0	0	0
200 (Replicate of 41)	Severity	--	--	0	--	--	0	--
	Extent	--	--	0	--	0.0	0	0

*Based on the standard procedures used by each device or method. (Number in parenthesis is distress in square feet).

**Includes all cracking and patching.

Note: 1 square foot = 0.0929 square meter.

Table 15. Comparison of reported alligator cracking for flexible pavement sections (continued).

SECTION	DISTRESS *	MAPPING (Square Feet)	DETAILED VISUAL SURVEY		GERPHO (Square Feet)	PASCO** (Crack Ratio %)	ARAN (Percent of Area)	LASER RST (Percent of Area)
			Manual (Square Feet)	Automated Data Logger (Percent of Area)				
55 (Initial)	Severity	0	0	0	0	--	0	--
	Extent	0	0	0	0	0.9	0	0
55 (Repeat)	Severity	--	--	--	--	--	0	--
	Extent	--	--	--	--	0.9	0	0
4 (Initial)	Severity	Low	Low, Moderate	Low,Moderate	Low	--	0	--
	Extent	275	472	51-80% (5610-8800)	580	6.2	0	0
4 (Repeat)	Severity	--	--	--	--	--	0	--
	Extent	--	--	--	--	6.0	0	0
44 (Initial)	Severity	Low	Low, Moderate	Low	Low	--	Low	--
	Extent	1310	1195	1-10% (100-1000)	934	5.4	10% (1000)	0
44 (Repeat)	Severity	--	--	--	--	--	Low	--
	Extent	--	--	--	--	5.6	10% (1000)	0
201 (Replicate of 44)	Severity	--	--	Low,Moderate	--	--	Low	--
	Extent	--	--	1 - 10% (100 - 1000)	--	5.4	10% (1000)	0
56 (Initial)	Severity	Low, Moderate	Low,High, Moderate	Moderate	Low	--	Low,Mod., High	--
	Extent	5400	3250	81-100% (8100-10000)	7271	72.6	20-40% (2000-4000)	Over 33% (3300)
56 (Repeat)	Severity	--	--	--	--	--	Low, High	--
	Extent	--	--	--	--	72.4	20-40% (2000-4000)	Over 33% (3300)
300	Severity	0	Moderate	0	Low	--	0	--
	Extent	0	25	0	171	2.0	0	0

*Based on the standard procedures used by each device or method. (Number in parenthesis is distress in square feet).

**Includes all cracking and patching.

Note: 1 square foot = 0.0929 square meter.

Table 16. Comparison of reported longitudinal cracking for flexible pavement sections.

SECTION	DISTRESS *	MAPPING (Linear Feet)	DETAILED VISUAL SURVEY		GERPHO (Linear Feet)	PASCO** (Crack Ratio, %)	ARAN (Linear Feet)	LASER RST (Crack Width)
			Manual *** (Linear Feet)	Automated Data Logger (Quantity)				
F1	Severity	Low	Low	Low	Low	--	Moderate	--
	Extent	415	231	1 (1000)	118	1.1	9-90	0
7 (Initial)	Severity	Low	0	0	Low	--	Moderate	--
	Extent	175	0	0	158	2.2	3-30	0
7 (Replicate)	Severity	--	--	0	--	--	Low	--
	Extent	--	--	0	--	2.1	240-640	0
19	Severity	0	0	0	Low	--	0	--
	Extent	0	0	0	31	0.0	0	0
F4	Severity	Low	Low	0	Low	--	0	--
	Extent	500	62	0	53	6.6	0	0
100 (Replicate of F4)	Severity	--	--	0	Low	--	0	--
	Extent	--	--	0	32	6.5	0	0
41 (Initial)	Severity	Low	0	Low	Low	--	Low	--
	Extent	650	0	1 (1000)	239	0.0	30-80	0
41 (Repeat)	Severity	--	--	--	--	--	Low	--
	Extent	--	--	--	--	0.0	170-480	<0.5 in.
200 (Replicate of 41)	Severity	--	--	0	--	--	Low	--
	Extent	--	--	0	--	0.0	470-1360	0

*Based on the standard procedures used by each device or method. (Number in parenthesis is distress in linear feet).

**Includes all cracking and patching.

***Includes transverse and longitudinal cracking.

Note: 1 linear foot = 0.3048 m.

Table 16. Comparison of reported longitudinal cracking for flexible pavement sections (continued).

SECTION	DISTRESS *	MAPPING (Linear Feet)	DETAILED VISUAL SURVEY		GERPHO (Linear Feet)	PASCO** (Crack Ratio,%)	ARAN (Linear Feet)	LASER RST (Crack Width)
			Manual *** (Linear Feet)	Automated Data Logger (Quantity)				
55 (Initial)	Severity	Low	Low	0	Low	--	0	--
	Extent	695	333	0	3	0.9	0	0
55 (Repeat)	Severity	--	--	--	--	--	0	--
	Extent	--	--	--	--	0.9	0	0
4 (Initial)	Severity	Low, Moderate	Low, Moderate	Moderate	Low	--	Low, Moderate	--
	Extent	1170	175	1 (1000)	498	6.2	223-670	<0.5 in.
4 (Repeat)	Severity	--	--	--	--	--	Low, Moderate	--
	Extent	--	--	--	--	6.0	520-1520	<0.5 in.
44 (Initial)	Severity	Low, Moderate	0	Moderate	Low	--	Low	--
	Extent	645	0	1 (1000)	198	5.4	880-2160	<0.5 in.
44 (Repeat)	Severity	--	--	--	--	--	Low	--
	Extent	--	--	--	--	5.6	400-1200	<0.5in.
201 (Replicate of 44)	Severity	--	--	0	--	--	Low, Moderate	--
	Extent	--	--	0	--	5.4	410-1200	<0.5 in.
56 (Initial)	Severity	Low, Moderate	0	High	Low	--	Low	--
	Extent	610	0	1 (1000)	91	72.6	430-1280	>0.5 in.
56 (Repeat)	Severity	--	--	--	--	--	Low, Moderate	--
	Extent	--	--	--	--	72.4	60-160	>0.5%
300	Severity	Low	Low	0	Low	--	Low	--
	Extent	260	215	0	76	2.0	30-80	<0.5%

*Based on the standard procedures used by each device or method. (Number in parenthesis is distress in linear feet).

**Includes all cracking and patching.

***Includes transverse and longitudinal cracking.

Note: 1 linear foot = 0.3048 m.

Table 17. Comparison of reported transverse cracking for flexible pavement sections.

SECTION	DISTRESS *	MAPPING (Linear Feet)	DETAILED VISUAL SURVEY Manual *** (Linear Feet)	DETAILED VISUAL SURVEY Automated Data Logger (Quantity)	GERPHO (Linear Feet)	PASCO** (Crack Ratio, %)	ARAN (Crack Spacing, feet)	LASER RST (Quantity)
F1	Severity	0	Low	Low	Low	--	Low	--
	Extent	0	231	1-5 (12-60)	17	1.1	>250	6
7 (Initial)	Severity	0	0	Low	Low	--	0	--
	Extent	0	0	1-5 (12-60)	18	2.2	0	30
7 (Replicate)	Severity	--	--	Low	--	--	0	--
	Extent	--	--	1-5 (12-60)	--	2.1	0	37
19	Severity	0	0	0	0	--	0	--
	Extent	0	0	0	0	0.0	0	0
F4	Severity	Low	Low	Low	Low	--	Low	--
	Extent	70	62	1-5 (12-60)	45	6.6	100-250	18
100 (Replicate of F4)	Severity	--	--	Low	Low	--	0	--
	Extent	--	--	6-10 (72-120)	35	6.5	0	15
41 (Initial)	Severity	0	0	0	0	--	0	--
	Extent	0	0	0	0	0.0	0	15
41 (Repeat)	Severity	--	--	--	--	--	0	--
	Extent	--	--	--	--	0.0	0	3
200 (Replicate of 41)	Severity	--	--	0	--	--	0	--
	Extent	--	--	0	--	0.0	0	64

*Based on the standard procedures used by each device or method. (Number in parenthesis is distress in linear feet).

**Includes all cracking and patching.

***Includes transverse and longitudinal cracking.

Note: 1 linear foot = 0.3048 m.

Table 17. Comparison of reported transverse cracking for flexible pavement sections (continued).

SECTION	DISTRESS *	MAPPING (Linear Feet)	DETAILED VISUAL SURVEY		GERPHO (Linear Feet)	PASCO** (Crack Ratio, %)	ARAN (Crack Spacing, feet)	LASER RST (Quantity)
			Manual *** (Linear Feet)	Automated Data Logger (Quantity)				
55 (Initial)	Severity	Low	Low	0	Low	--	0	--
	Extent	60	333	0	54	0.9	0	6
55 (Repeat)	Severity	--	--	--	--	--	0	--
	Extent	--	--	--	--	0.9	0	6
4 (Initial)	Severity	Low	Low, Moderate	0	Low	--	0	--
	Extent	165	175	0	6	6.2	0	0
4 (Repeat)	Severity	--	--	--	--	--	0	--
	Extent	--	--	--	--	6.0	0	0
44 (Initial)	Severity	Low	0	Low	Low	--	0	--
	Extent	140	0	6-10 (60-100)	64	5.4	0	6
44 (Repeat)	Severity	--	--	--	--	--	0	--
	Extent	--	--	--	--	5.6	0	0
201 (Replicate of 44)	Severity	--	--	0	--	--	0	--
	Extent	--	--	0	--	5.4	0	3
56 (Initial)	Severity	0	0	0	0	--	0	--
	Extent	0	0	0	0	72.6	0	357(a)
56 (Repeat)	Severity	--	--	--	--	--	0	--
	Extent	--	--	--	--	72.4	0	381(a)
300	Severity	Low, Moderate	Low	Low	Low	--	0	--
	Extent	95	215	6-10 (60-100)	95	2.0	0	0

*Based on the standard procedures used by each device or method. (Number in parenthesis is distress in linear feet).

**Includes all cracking and patching.

***Includes transverse and longitudinal cracking.

(a)Includes alligator and transverse cracking.

Note: 1 linear foot = 0.3048 m.

Table 18. Comparison of reported potholes/patching for flexible pavement sections.

SECTION	DISTRESS *	MAPPING (Quantity/ Square Feet)		DETAILED VISUAL SURVEY			GERPHO (Quantity /Square Feet)		PASCO** (Patching Ratio,%)	ARAN (Quantity of potholes only)	LASER RST
				Manual (Quantity/ Square Feet)		Automated Data Logger *** (Quantity)					
F1	Severity	0	0	0	0	0	--	--	--	0	--
	Extent	0	0	0	0	0	0	0	0.0	0	--
7 (Initial)	Severity	0	Good	0	Low	0	--	--	--	Low	--
	Extent	0	1870	0	3355	0	0	0	0.0	1	--
7 (Replicate)	Severity	--	--	--	--	--	--	--	--	0	--
	Extent	--	--	--	--	--	--	--	0.0	0	--
19	Severity	0	0	0	0	0	--	--	--	0	--
	Extent	0	0	0	0	0	0	0	0.0	0	--
F4	Severity	0	Good	0	Low	Poor	--	--	--	0	--
	Extent	0	55	0	102	1-2	1	0	0.0	0	--
100 (Replicate of F4)	Severity	--	--	--	--	Good	--	--	--	0	--
	Extent	--	--	--	--	1-2	1	0	0.0	0	--
41 (Initial)	Severity	0	0	0	0	0	--	--	--	0	--
	Extent	0	0	0	0	0	1	11	0.0	0	--
41 (Repeat)	Severity	--	--	--	--	--	--	--	--	0	--
	Extent	--	--	--	--	--	--	--	0.0	0	--
200 (Replicate of 41)	Severity	--	--	--	--	--	--	--	--	0	--
	Extent	--	--	--	--	--	--	--	0.0	0	--

*Based on the standard procedures used by each device or method.

**Includes only area of emergent repair.

***Quantity includes potholes and patches less than 50 ft. long.

Note: 1 square foot = 0.0929 square meter.

Table 18. Comparison of reported potholes/patching for flexible pavement sections (continued).

SECTION	DISTRESS *	MAPPING (Quantity/ Square Feet)		DETAILED VISUAL SURVEY Manual (Quantity/ Square Feet)		DETAILED VISUAL SURVEY Automated Data Logger *** (Quantity)	GERPHO (Quantity/ Square Feet)		PASCO** (Patching Ratio, %)	ARAN (Quantity of Potholes only)	LASER RST
55 (Initial)	Severity	Poor	Good	Low	Low	Poor	--	--	--	Low	--
	Extent	5	60	1	1169	1-2	2	22	22.9	1	--
55 (Repeat)	Severity	--	--	Low, High	Mod.	--	--	--	--	Low	--
	Extent	--	--	2	4	--	--	--	22.9	1	--
4 (Initial)	Severity	Poor	0	--	--	Good	--	--	--	High	--
	Extent	5	0	--	--	3-5	1	11	0.0	1	--
4 (Repeat)	Severity	--	--	--	--	--	--	--	--	High	--
	Extent	--	--	--	--	--	--	--	0.0	2	--
44 (Initial)	Severity	0	Poor	0	Low	0	--	--	--	0	--
	Extent	0	230	0	2420	0	1	22	0.1	0	--
44 (Repeat)	Severity	--	--	--	--	--	--	--	--	0	--
	Extent	--	--	--	--	--	--	--	0.1	0	--
201 (Replicate of 44)	Severity	--	--	--	--	--	--	--	--	0	--
	Extent	--	--	--	--	--	--	--	0.1	0	--
56 (Initial)	Severity	Poor	Poor, Good	L,M,H	L,M,H	Poor	--	--	--	High	--
	Extent	65	25	14	2229	21-30	24	140	0.5	30	--
56 (Repeat)	Severity	--	--	--	--	--	--	--	--	High	--
	Extent	--	--	--	--	--	--	--	0.5	10	--
300	Severity	0	0	0	Mod.	Poor	--	--	--	0	--
	Extent	0	0	0	30	1-2	0	11	0.0	0	--

*Based on the standard procedures used by each device or method.
**Includes only area of emergent repair.
***Quantity includes potholes and patches less than 50 ft. long.

Note: 1 square foot = 0.0929 square meter.

Table 19. Comparison of reported rutting for flexible pavement sections.

SECTION	DISTRESS *	MAPPING (Square Feet)	DETAILED VISUAL SURVEY		GERPHO	PASCO (Inches)	ARAN ** (Inches)	LASER RST (Inches)
			Manual (Square Feet)	Automated Data Logger				
F1	Severity	0	0	0	--	--	--	--
	Extent	0	0	0	--	--	0.36	0.11
7 (Initial)	Severity	--	Low	Low	--	--	--	--
	Extent	--	150	Throughout	--	0.20	0.42	0.08
7 (Replicate)	Severity	--	--	Low	--	--	--	--
	Extent	--	--	Local	--	0.24	0.34	0.09
19	Severity	0	0	Low	--	--	--	--
	Extent	0	0	Throughout	--	0.59	0.46	0.18
F4	Severity	0	0	Low	--	--	--	--
	Extent	0	0	Local	--	--	0.39	0.15
100 (Replicate of F4)	Severity	--	--	Low	--	--	--	--
	Extent	--	--	Throughout	--	--	0.53	0.13
41 (Initial)	Severity	--	Low,Mod., High	Low	--	--	--	--
	Extent	--	1588	Throughout	--	1.46	0.46	0.37
41 (Repeat)	Severity	--	--	--	--	--	--	--
	Extent	--	--	--	--	1.42	0.27	0.33
200 (Replicate of 41)	Severity	--	--	Low	--	--	--	--
	Extent	--	--	Throughout	--	--	0.46	0.37

* Based on the standard procedures used by each device or method.

** Maximum of reported left and right wheelpath values.

Note: 1 square foot = 0.0929 meter, 1 inch = 25.4 mm.

Table 19. Comparison of reported rutting for flexible pavement sections (continued).

SECTION	DISTRESS *	MAPPING (Square Feet)	DETAILED VISUAL SURVEY		GERPHO	PASCO (Inches)	ARAN** (Inches)	LASER RST (Inches)
			Manual (SquareFeet)	Automated Data Logger				
55 (Initial)	Severity	0	Low, Moderate	Low	--	--	--	--
	Extent	0	1413	Throughout	--	0.71	0.42	0.24
55 (Repeat)	Severity	--	--	--	--	--	--	--
	Extent	--	--	--	--	0.67	0.33	0.24
4 (Initial)	Severity	Moderate	Low,Mod., High	Moderate	--	--	--	--
	Extent	6000	4075	Throughout	--	1.34	0.41	0.30
4 (Repeat)	Severity	--	--	--	--	--	--	--
	Extent	--	--	--	--	1.50	0.35	0.32
44 (Initial)	Severity	Low,Mod., High	Low,Mod., High	High	--	--	--	--
	Extent	6000	703	Throughout	--	1.93	0.65	0.43
44 (Repeat)	Severity	--	--	--	--	--	--	--
	Extent	--	--	--	--	1.93	0.55	0.37
201 (Replicate of 44)	Severity	--	--	Moderate, High	--	--	--	--
	Extent	--	--	Throughout(M), Local(H)	--	--	0.81	0.44
56 (Initial)	Severity	Moderate, High	Low,Mod., High	High	--	--	--	--
	Extent	7000	5938	Throughout	--	2.84	0.88	1.22
56 (Repeat)	Severity	--	--	--	--	--	--	--
	Extent	--	--	--	--	3.11	--	1.34
300	Severity	0	Low	Moderate	--	--	--	--
	Extent	0	75	Local	--	1.46	0.49	0.20

* Based on the standard procedures used by each device or method.

** Maximum of reported left and right wheelpath values.

Note: 1 square foot = 0.0929 meter, 1 inch = 25.4 mm.

In reporting transverse cracks, all three visual methods disagreed on the extent. Mapping reported no cracking, the manual method reported over 200 linear feet (61 m) of low severity cracks, and the data logger reported 12 to 60 linear feet (3.7 to 18.3 m) of transverse cracking. However, mapping was done on two 100-foot (30.5 m) subsections and it is possible that all of the transverse cracking occurred in the remaining 800 feet (244 m). GERPHO reported 17 feet (5.2 m) of transverse cracking. ARAN reported a crack spacing of greater than 250 feet (76.2 m) (or less than 4 cracks for the 1000-foot (305 m) section). The Laser RST reported 6 cracks.

None of the methods or devices reported any potholes or patching on Section F1.

The three visual methods reported no rutting. ARAN and the Laser RST reported rut depths of 0.36 and 0.11 inches (9 and 3 mm), respectively.

Section 7

Section 7 was considered a relatively good flexible section. It was located on the outside lane of southbound US 183, a four-lane divided highway. A replicate run was done on a different day, after the initial run. However, the section numbering could not be changed prior to the second test, thus the replicate run was also identified as Section 7.

The three methods of visual survey rating reported alligator cracking to be the same severity and roughly the same extent (about 100 square feet or 9.3 square meters). GERPHO reported a slightly lower amount of alligator cracking, PASCO reported a crack ratio of approximately two percent (which included all types of cracking and patching) for initial and replicate runs. Laser RST did not report any alligator cracking on initial or replicate runs. ARAN reported no alligator cracking on the initial run of Section 7, but on the repeat run, a small amount of low severity alligator cracking was reported.

For longitudinal cracking, mapping, GERPHO, and ARAN reported the distress present. The manual and data logger surveys failed to report any longitudinal cracking. The data logger defined a longitudinal crack as a crack running (or equivalent cracks) the full length of a 1000-foot (305 m) section. Thus, the rater may have found a small amount of cracking but it would not have been reported. The Laser RST reported no longitudinal cracks. The replicate runs for the data logger, ARAN, and the Laser RST reported approximately the same results.

In the case of transverse cracking, mapping and the manual detailed survey reported that no transverse cracks were present. However, the data logger reported a range of one to five low severity transverse cracks on initial and replicate runs. Because of this discrepancy, Section 7 was rechecked for transverse cracks and this time, six transverse cracks were reported (not shown on table). The Laser RST reported about 30 transverse cracks for initial and replicate runs, ARAN reported no cracking on either run, and GERPHO reported 18 linear feet (5.5 m) of transverse cracking.

No potholes were reported for Section 7. Both mapping and the manual detailed survey reported large quantities of patching while the data logger reported zero patching. This appears to be conflicting, however, on Section 7 the patches were extremely long, and the automated data logger disregarded patches longer than 50 feet (15.2 m) (assumes the patch was done properly and thus not considered to be a distress). GERPHO reported no patching for this section. PASCO also reported a patch ratio of zero, however, PASCO's patching ratio is defined as areas requiring repair and thus may not include a patch in good condition.

Low severity rutting was reported by both detailed visual surveys. The Laser RST reported the smallest rut depth, 0.08 inches (2.0 mm), 0.09 inches (2.3 mm), ARAN the largest, 0.42 inches (10.7 mm), 0.34 inches (8.6 mm), and PASCO, 0.020 inches (5.1 mm), 0.24 inches (6.1 mm), on initial and replicate runs, respectively.

Section 19

Section 19, a flexible section in good condition, was located on US 183 in the northbound, outside lane. US 183 is a heavily traveled, four-lane divided highway at this location.

The three visual distress surveys reported no alligator cracking in Section 19. In addition, no longitudinal cracking, transverse cracking, potholes, or patching was reported by these visual survey methods. GERPHO reported a small amount of low severity alligator cracking, and longitudinal cracking on this section, but no transverse cracking and no potholes or patching. PASCO's crack ratio was reported to be zero for this section and ARAN also reported no cracking or potholes. The Laser RST reported 30 transverse cracks, and no longitudinal or alligator cracking.

For rutting, the data logger reported low severity rutting throughout the entire section, while mapping and the manual method reported no rutting. This discrepancy can be attributed to the rutting definitions for each method. Mapping and the manual method considered rutting to be zero when the rut depth was between zero and 0.25 inches (6 mm). Low severity rutting occurred when the rut depth was between 0.25 inches (6 mm) and 0.50 inches (13 mm). For the data logger, rutting was zero only when the rut depth was equal to zero and rutting was low when rut depth was between zero and 0.25 inches (6 mm). The automated devices reported rut depths of about 0.25 to 0.50 inches (6 to 13 mm).

Section F4

A second test section on SH 71 was F4. Section F4 was classified as a moderate flexible section. Section F4 was located on the westbound, outside lane of SH 71, directly across the median from Section F1. Section 100 was the blind replicate run of Section F4.

When rating alligator cracking, the three methods of visual survey agreed that low severity alligator cracking existed. GERPHO and ARAN also reported alligator cracking. The Laser RST did not report any alligator cracking and PASCO reported a crack ratio of around six percent (however, this ratio included all cracking and patching). All replicate runs for the data logger, GERPHO, PASCO, and ARAN showed approximately the same values for alligator cracking.

Both mapping and the manual visual survey reported low severity longitudinal cracking. The data logger did not report any longitudinal cracking, however a longitudinal crack was defined as full length, therefore cracking less than 1000 linear feet (305 m) could have been identified. GERPHO also reported low severity longitudinal cracking. ARAN and the Laser RST did not report any longitudinal cracking. All replicate runs reported approximately the same values as the initial test for longitudinal cracking.

All three methods of visual survey agreed that transverse cracking was low in severity and roughly sixty linear feet. The data logger reported slightly more cracking on the replicate run. GERPHO also reported low severity cracking (about 40 linear feet or 12.2 m). ARAN reported low severity cracking in the initial run but no cracking in the replicate run. The Laser RST reported about 15 transverse cracks for this section.

Mapping reported 55 square feet (5.1 square meters) of good patch. The manual method reported 102 square feet (9.5 square meters) of low severity patch. The data logger reported one to two poor potholes/patches (no distinction is made between patches and potholes). The data logger was completed before the other two visual methods and two large potholes existed in that section. Before the other visual methods rated the section, F4 was patched in these pothole areas. Thus, the data logger rated 100 (replicate of F4) and reported 1 to 2 good patches. GERPHO identified one high severity pothole and no patching. PASCO reported a patching ratio as zero (however, as stated earlier, this ratio included only area of emergent repair). ARAN reported no potholes.

The manual method and mapping reported zero rutting, i.e. rutting less than 0.25 inches (6 mm). The data logger reported low severity rutting, i.e. rutting between zero and 0.25 inches (6 mm). Rutting in localized areas was noted in the first run and rutting throughout the section was noted in the replicate run. ARAN and the Laser RST reported rut depths of between 0.13 and 0.53 inches (33 and 135 mm) for the initial and replicate runs. PASCO's ROADRECON-75 was not operated on this section for rut depth measurement.

Section 41

Section 41 was considered a moderate section. Section 41 was located on the southbound, outside lane of FM 3177, a four lane highway. A repeat run and a replicate run (200) was done.

Mapping reported no alligator cracking and low severity longitudinal cracking. The manual method reported low severity alligator cracking and no longitudinal cracking. The automated data logger reported low severity alligator and longitudinal cracking on the initial run and no alligator or longitudinal cracking on the replicate run. Because of these discrepancies, Section 41 was carefully rechecked (not shown on tables). This time, no alligator cracking was reported and approximately 60 linear feet (18.3 m) of low severity longitudinal cracking was reported. GERPHO reported approximately 1500 square feet (135 square meters) of alligator cracking and 200 linear feet (61 m) of longitudinal cracking. PASCO reported a crack ratio of zero. ARAN and the Laser RST reported no alligator cracking. ARAN reported low severity longitudinal cracking on the initial, repeat, and replicate runs. The Laser RST reported some longitudinal cracking on the repeat run but no cracking on the initial and replicate runs.

Mapping, manual survey, and automated survey reported no transverse cracking or patching. The Laser RST reported 15 transverse cracks on the first run, 3 on the repeat run, and 64 on the replicate run. No other method reported transverse cracks. GERPHO reported 11 square feet (1.0

square meters) of patching and one pothole. No other method reported potholes.

The manual survey method recorded low, moderate, and high severity rutting over most of the wheel paths. The automated method indicated only low severity rutting throughout the section for initial and replicate runs. Since the automated survey rater estimated these quantities, an additional inspection was conducted (not shown on tables), and it confirmed the reports of the manual survey method. Low, moderate, and high severity rutting was found in localized portions of the section. Measured rut depths varied among the automated methods. PASCO reported depths of about 1.4 inches (36 mm) for both initial and repeat runs. ARAN reported 0.46 inches (12 mm) for initial and replicate runs but 0.27 inches (7 mm) for the repeat run. The Laser RST reported approximately 0.35 inches (9 mm) for initial, repeat, and replicate runs.

<u>Section 55</u>

Section 55 was a flexible section considered to be in moderate condition and located on the outside westbound lane of FM 969, a four-lane highway. A repeat run was done on Section 55.

The three visual survey rating methods reported no alligator cracking. GERPHO, ARAN, and the Laser RST also reported no alligator cracking. PASCO reported a low crack ratio (one percent) but this number included all cracking and patching.

Mapping and the manual detailed survey reported low severity longitudinal cracking less than 1000 feet (305 m). The data logger reported no longitudinal cracking, however, it defined one crack as being 1000 feet (305 m) long (the section length). GERPHO reported a relatively small amount (compared to the visual methods) of longitudinal cracking. ARAN and the Laser RST reported no longitudinal cracking on either run.

Although both mapping and the manual survey reported low severity transverse cracking, the extent differed greatly. However, mapping was an estimate based on random samples. The data logger did not report any transverse cracking. ARAN reported no transverse cracks on initial and replicate runs. The Laser RST reported six transverse cracks on both initial and replicate runs.

Mapping reported 60 square feet (5.6 square meters) of good patching and 5 potholes. The manual survey reported 1169 square feet (108.6 square meters) of low severity patching and one pothole. The data logger reported one to two poor potholes/patches. GERPHO reported two potholes and 22 square feet (2.0 square meters) of patching. ARAN reported one pothole. PASCO reported a patching ratio of 23 percent (however this number includes area of emergent repair).

For rutting, mapping indicated zero rutting, Paver recorded 1413 square feet (131.3 square meters) of low and moderate rutting, and Paveman indicated low rutting throughout the section. The Laser RST showed the lowest rut depth (0.24 inches (6 mm) on both runs), ARAN reported 0.42 inches (11 mm) on the first run and 0.33 inches on the repeat run, and PASCO reported 0.71 inches (18 mm) and 0.67 inches (17 mm) on the initial and repeat runs, respectively.

Section 4

Decker Lake Road, a two-lane road, was the location of Section 4. Section 4 was on the eastbound side and was considered to be in poor condition. A repeat run was done the same day.

All visual survey methods showed low severity alligator cracking. The detailed visual surveys also reported moderate alligator cracking. The data logger estimated an extremely high percentage, compared to the other methods. It was discovered later that the rater mistakenly reported edge cracking and edge deterioration as alligator cracking. GERPHO reported low severity alligator cracking, but ARAN and the Laser RST did not report any alligator cracking on either run. PASCO reported a crack ratio of six percent.

All visual methods reported moderate longitudinal cracking. Mapping and the manual survey reported low severity also. GERPHO reported low severity cracking, ARAN identified low and moderate cracking and the Laser RST identified some longitudinal cracks with widths less than 0.5 inches (13 mm).

Mapping and the manual survey method reported roughly equal extents of transverse cracking, but disagreed upon severity; low for mapping while low and moderate for the other. The data logger reported zero transverse cracks, as did ARAN and Laser RST. GERPHO reported 6 linear feet of cracking.

Mapping indicated no patching while the two detailed surveys and GERPHO reported some patch(es). (The data logger combined potholes and patches, but rates all potholes as poor. Since it indicated a quantity of three to five good patches/potholes, it can be inferred that only patches were found). Mapping reported five potholes, the manual method reported two potholes, and both GERPHO and ARAN reported one pothole.

Mapping showed 6000 square feet (557 square meters) of moderate rutting, while the manual survey reported 4075 square feet (379 square meters) of low, moderate, and high rutting. The data logger reported rutting as moderate throughout the section. Because of this discrepancy, a second rater was sent to rate Section 4 again (not shown on tables) and localized areas of low, moderate, and high rutting were found, which agreed with the manual method. The two sample sections mapped may have contained only moderate rutting, while the low and high rutting occurred in the other subsections. PASCO reported a rut depth of 1.34 inches (34 mm), ARAN 0.41 inches (10 mm), and the Laser RST, 0.30 inches (8 mm).

Section 44

Section 44, a flexible section in poor condition, was also situated on Decker Lake Road, a two-lane road, in the eastbound direction. A repeat run and a replicate run (201) was done for Section 44.

Visual survey methods agreed that low severity alligator cracking existed. The manual survey method also reported moderate severity. All visual methods agreed upon the extent (about 1000 square feet or 93 square meters). GERPHO and ARAN also agreed upon the extent and severity of alligator cracking. The Laser RST reported no alligator cracking. PASCO reported a crack ratio of about five percent but this number included all cracking and patching.

The manual survey method combined longitudinal and transverse cracking. For Section 44, it reported zero longitudinal and transverse cracks, while mapping showed 645 linear feet (197 m) of low and moderate longitudinal cracking and the data logger showed 1000 feet (305 m) of moderate longitudinal cracking. In this case, the manual method may have counted some longitudinal cracks as low level alligator cracking. GERPHO, ARAN, and the Laser RST all reported some longitudinal cracking.

Mapping reported 140 linear feet (42.7 m) of low severity transverse cracking and the data logger reported 60 to 100 linear feet (18.3 to 30.5 m) of low severity cracking. GERPHO also reported some low severity transverse cracks. ARAN reported no transverse cracks. The Laser RST reported some transverse cracks on the initial and replicate runs but zero cracks on the repeat run.

For patching, mapping reported 230 square feet (21.4 square meters), the manual survey method reported 2420 square feet (225 square meters) of low severity patching, and the data logger reported zero patching. The data logger reported zero although long patches (greater than 50 feet or 15.2 m long) were found on this section because it did not rate patches greater than 50 feet (15.2 m) long. Mapping reported a low extent of patching due to the small portion of the large patch that was in the subsection mapped. GERPHO reported a small amount of patching (22 square feet or 2.0 square meters) and one pothole. No potholes were reported by any other methods.

Mapping and the manual survey method agreed that low, moderate, and high rutting existed. The data logger claimed high rutting throughout the section, but the replicate run showed localized high and moderate rutting throughout the section. Because of this discrepancy, the section was carefully rechecked for rutting (not shown on tables) and localized low, moderate, and high rutting was found. Rut depth was also measured, manually, every 50 feet (15.2 m) and the maximum values found in the left and right wheelpaths were recorded (Table 40). These values can be compared directly to the values reported by PASCO (ROADRECON-75). ARAN reported average values obtained by ultrasonic sensors in the left and right wheelpaths. The Laser RST measured the maximum rut depth every 10 centimeters and then reported an average of these measured values for each subsection.

To compare these measurements more easily, the mean and standard deviation for each method was calculated as follows:

Method	Mean (inches)	Standard Deviation (inches)
Manual Measurement	0.573	0.568
PASCO	0.534	0.461
ARAN	0.433	0.391
Laser RST	0.453	0.128

Note: 1 inch = 25.4 mm

Both the Laser RST and ARAN reported values lower than those reported by manually measuring. PASCO reported a rut depth within 7 percent of that reported by the manual measurement. However, these measurements cannot all be directly compared because measurements were taken at different intervals and with different procedures. Appendix A provides details on the procedures used by PASCO, ARAN, and Laser RST to measure rut depths.

<u>Section 56</u>

Section 56 was a flexible section considered to be in poor condition. It was located on the northbound lane of Greg Manor Road, a two lane road. A repeat run was done for Section 56.

Table 40. Rut depth in inches as measured by various devices, Test Section 44.

Section Length (ft.)	Manual Measurement (a)		PASCO(a)		ARAN(b)		Laser RST(c)
	LWP	RWP	LWP	RWP	LWP	RWP	
0	0.19	0.44	0.12	0.28			
50	0.19	0.56	0.12	0.98			
100	0.25	0.75	0.35	0.55	0.63	0.89	0.39
150	0.38	0.56	0.51	0.20			
200	0.31	1.38	0.20	0.63	0.21	1.16	0.41
250	0.13	0.31	0.20	0.12			
300	0.38	0.31	0.47	0.98	0.0	0.29	0.55
350	0.38	1.19	0.28	1.42			
400	0.25	0.75	0.12	0.43	0.24	0.37	0.34
450	0.25	0.38	0.20	0.83			
500	0.19	0.44	0.16	0.43			0.47
550	0.19	2.25	0.12	1.26	0.0	0.38	
600	0.0	1.00	0.24	1.46			0.63
650	0.25	2.13	0.75	1.93	0.0	0.70	
700	0.31	1.31	0.67	1.26			0.43
750	0.13	0.25	0.20	0.20	0.39	0.37	
800	0.44	0.50	0.28	0.67			0.35
850	0.25	0.13	0.24	0.31	0.49	0.32	
900	0.25	0.69	0.28	0.51			0.26
950	0.19	2.25	0.20	0.55	0.0	1.36	
1000	0.19	1.38	0.16	1.54			0.46 0.69

(a) Maximum rut depth measured every fifty feet.
(b) Average rut depth of 0.02 mile subsections.
(c) Average (30m subsections) of maximum rut depths measured every 10 cm.

Note: 1 inch = 25.4 mm

Mapping reported 5400 square feet (502 square meters) of low and moderate alligator cracking. The manual survey method indicated 3250 square feet (302 square meters) of low, moderate, and high alligator cracking. The data logger reported 8100 to 10,000 square feet (752 to 929 square meters) (81 to 100 percent) of moderate alligator cracking. Because of this discrepancy, Section 56 was rechecked for alligator cracking (not shown on table). Alligator cracking was found on approximately 81 to 100 percent of the wheel path area (about 4000 to 6000 square feet or 372 to 557 square meters) and not 81 to 100 percent of the total area. GERPHO reported approximately 7000 square feet (650 square meters) of low severity alligator cracking. ARAN reported low, moderate, and high severity alligator cracking (2000 to 4000 square feet or 186 to 372 square meters) and the Laser RST reported over 3300 square feet (307 square meters) of alligator cracking. PASCO reported a crack ratio of 73 percent (which includes all types of cracking and patching).

Mapping estimated 610 feet (186 m) of low and moderate severity longitudinal cracking. The data logger reported 1000 feet (305 m) of longitudinal cracking. The manual survey method combined longitudinal and transverse cracking and reported zero cracking. For this section, it reported edge cracking (defined as cracks one to two feet from the edge) and upon rechecking the section, it was found that most of the longitudinal cracking occurred about a foot away from the edge. GERPHO reported about 90 linear feet (27 m) of low severity longitudinal cracking, ARAN also reported low severity cracking, and the Laser RST reported longitudinal cracks with widths greater than 0.5 inches (13 mm). On ARAN's repeat run, low and moderate cracking was observed. No transverse cracking was observed by GERPHO, ARAN or any of the visual methods. The Laser RST reported a large quantity of transverse cracks, however, this was reported to include alligator cracking.

Mapping reported 25 square feet (2.3 square meters) of patching, both good and poor, and 65 potholes. The manual survey method indicated 2229 square feet (207 square meters) of low, moderate, and high severity patching and 14 potholes. The data logger gave a range of 21 to 30 poor potholes/patches. Section 56 was rechecked because of the discrepancy with patching area. An old overlay that was raveling and weathering was reported. The manual visual survey may have included this old overlay as part of the patching area. GERPHO reported 140 square feet (13 square meters) of patching and 24 potholes. ARAN reported 30 potholes on the first run and 10 on the repeat run. PASCO reported a low patching ratio (0.5 percent).

All visual methods agreed that a high severity and amount of rutting existed. PASCO reported a rut depth of about 3 inches (76 mm) for initial and repeat runs. The Laser RST reported a rut depth of about 1.3 inches (33 mm) for both runs. ARAN reported a rut depth of 0.9 inches (23 mm).

Section 300

Section 300, considered in poor condition, was located on the westbound, outside lane of Bee Caves Road, a four lane road known also as F.M. 2244. Of the visual methods, only the manual method reported 25 square feet (2.3 square meters) of moderate alligator cracking. The automated data logger rater noticed some alligator cracking in a small patch, but rated it in the patch category. GERPHO reported about 170 square feet (15.8 square meters) of low severity alligator cracking. ARAN and Laser RST reported no alligator cracking. PASCO reported a crack ratio of two percent.

Mapping results and manual survey methods both reported low severity and an extent of about 200 linear feet (61.0 m) of longitudinal cracking. The automated survey method reported no longitudinal cracking. However, the data logger recorded longitudinal cracks only in 1000-foot (305 m) increments. GERPHO reported 76 linear feet (23.2 m) of low severity cracking. ARAN also reported low severity cracking and Laser RST reported cracks with widths less than 0.5 inches (13 mm).

Mapping, manual survey, and automated survey methods agreed that low severity transverse cracks existed. The manual survey extent is higher due to the combination of transverse and longitudinal cracks. GERPHO reported 95 linear feet (29.0 m) of transverse cracking. ARAN and the Laser RST recorded no transverse cracks.

Mapping reported no patching and no potholes. The manual method reported small amounts of patching and no potholes. The automated data logger reported one to two potholes/patches. GERPHO reported 11 square feet (1.0 square meters) of patching and no potholes. ARAN reported no potholes.

Mapping produced results showing that no rutting existed. The manual survey method reported 75 square feet (7.0 square meters) of low severity rutting. The automated survey method reported localized sections of moderate rutting. PASCO reported a rut depth of almost 1.5 inches (38 mm), ARAN, a rut depth of 0.5 inches (13 mm), and the Laser RST reported 0.2 inches (5 mm).

RIGID PAVEMENT TEST SECTIONS

Tables 21 and 22 present a summary of the transverse cracking and map cracking/scaling/crazing reported to be found on the rigid pavement test sections by the various survey methods and devices. A section-by-section discussion and comparison of these distresses, and other distresses reported on the rigid test sections, follows.

Section R1

Section R1 was located on the southbound lane of the Columbus bypass on State Highway 71, a heavily trafficked, four-lane, divided highway. It was considered to be a section in good condition. It is a CRCP section.

The three visual survey methods reported transverse cracks. Mapping, however, only reported low levels of transverse cracks while the manual and automated survey methods reported both low and moderate levels. GERPHO and ARAN reported transverse cracking also. PASCO reported a crack ratio of 52 percent which included all types of linear cracking and areas of emergent repair. The RST was unable to detect these transverse cracks.

Table 21. Comparison of reported transverse cracking for rigid pavement sections.

SECTION	DISTRESS *	MAPPING (Quantity)	DETAILED VISUAL SURVEY		GERPHO (Quantity)	PASCO** (Crack Ratio, %)	ARAN (Crack Spacing, feet)	LASER RST (Quantity)
			Manual (Quantity)	Automated Data Logger (Quantity)				
R1 (CRCP)	Severity	Low	Low,Mod.	Low,Mod.	--	--	Low	--
	Extent	270	259	>40	154	52.0	20-50	--
R2 (Initial) (CRCP)	Severity	Low	Low,Mod., High	Low,Mod., High	--	--	Low	--
	Extent	270	258	>40	115	32.1	0-20	--
101 (Replicate of R2)	Severity	--	Low,Mod., High	Low,Mod., High	--	--	Low	--
	Extent	--	255	>40	--	31.8	>250	--
R3 (CRCP)	Severity	Low, Moderate	Low,Mod., High	Low,Mod., High	--	--	Low	--
	Extent	400	336	>40	283	91.9	0-20	119
R4 (JRCP)	Severity	0	0	0	--	--	0	--
	Extent	0	0	0	0	0.3	0	0
R5 (CRCP)	Severity	Low, Moderate	Low, Moderate	Low, Moderate	--	--	Low	--
	Extent	415	367	>40	312	101.0	0-20	134
R6 (CRCP)	Severity	Low, Moderate	Low,Mod., High	Low,Mod., High	--	--	Low	--
	Extent	385	368	>40	297	95.6	0-20	125
R7 (Initial) (JRCP)	Severity	0	0	0	--	--	0	--
	Extent	0	0	0	0	0.6	0	46
R7 (Repeat)	Severity	--	--	--	--	--	0	--
	Extent	--	--	--	--	0.7	0	55

* Based on the standard procedures used by each device or method.

** Includes all types of linear cracking and areas of emergent repair.

Note: 1 foot = 0.3048 m.

Table 21. Comparison of reported transverse cracking for rigid pavement sections (continued).

SECTION	DISTRESS *	MAPPING (Quantity)	DETAILED VISUAL SURVEY		GERPHO (Quantity)	PASCO** (Crack Ratio,%)	ARAN (Crack Spacing, feet)	LASER RST (Quantity)
			Manual (Quantity)	Automated Data Logger (Quantity)				
R8 (Initial) (CRCP)	Severity	Low, Moderate	Low,Mod., High	Low,Mod., High	--	--	Low	--
	Extent	320	325	>40	272	83.7	0-20	98
R8 (Repeat)	Severity	--	--	--	--	--	Low	--
	Extent	--	--	--	--	83.5	0-20	107
105 (Replicate of R8)	Severity	--	Low,Mod., High	Low,Mod., High	--	--	Low	--
	Extent	--	318	>40	--	101.0	0-20	--
R9 (CRCP)	Severity	Low, Moderate	Low Moderate	Low, Moderate	--	--	Low	--
	Extent	425	354	>40	296	94.0	0-20	153

* Based on the standard procedures used by each device or method.

** Includes all types of linear cracking and areas of emergent repair.

Note: 1 foot - 0.3048 m

Table 22. Comparison of reported map cracking/scaling/crazing for rigid pavement sections.

SECTION	DISTRESS *	MAPPING (Percent of Area)	DETAILED VISUAL SURVEY		GERPHO (Severity only)	PASCO	ARAN (Scaling only, Percent of Area)	LASER RST
			Manual (Severity only)	Automated Data Logger (Severity only)				
R1 (CRCP)	Severity	0	Low	Moderate	None	--	0	--
	Extent	0	--	--	--	--	0	--
R2 (Initial) (CRCP)	Severity	0	0	Low	None	--	0	--
	Extent	0	--	--	--	--	0	--
101 (Replicate of R2)	Severity	--	--	0	--	--	0	--
	Extent	--	--	--	--	--	0	--
R3 (CRCP)	Severity	Low	Moderate	Moderate	Low	--	0	--
	Extent	100%	--	--	--	--	0	--
R4 (JRCP)	Severity	Low	0	Low	--	--	0	--
	Extent	100%	--	--	--	--	0	--
R5 (CRCP)	Severity	Low	Low	Moderate	Low	--	0	--
	Extent	100%	--	--	--	--	0	--
R6 (CRCP)	Severity	Low	Moderate	High	Low	--	0	--
	Extent	95%	--	--	--	--	0	--
R7 (Initial) (JRCP)	Severity	Low, High	0	High	--	--	0	--
	Extent	100%	--	--	--	--	0	--
R7 (Repeat)	Severity	--	--	--	--	--	0	--
	Extent	--	--	--	--	--	0	--

* Based on the standard procedures used by each device or method.

Table 22. Comparison of reported map cracking/scaling/crazing for rigid pavement sections (continued).

SECTION	DISTRESS *	MAPPING (Percent of Area)	DETAILED VISUAL SURVEY		GERPHO (Severity only)	PASCO	ARAN (Scaling only, Percent of Area)	LASER RST
			Manual (Severity only)	Automated Data Logger (Severity only)				
R8 (Initial) (CRCP)	Severity	Low	Moderate	Low	Low	--	0	--
	Extent	94%	--	--	--	--	0	--
R8 (Repeat)	Severity	--	--	--	--	--	0	--
	Extent	--	--	--	--	--	0	--
105 (Replicate of R8)	Severity	--	--	Low	--	--	0	--
	Extent	--	--	--	--	--	0	--
R9 (CRCP)	Severity	Low	Low	Low	Low	--	0	--
	Extent	100%	--	--	--	--	0	--

* Based on the standard procedures used by each device or method.

Map cracking was reported on this section in low and moderate severity levels by the manual and automated survey methods, respectively. These two methods, however, did not report the extent of this distress. GERPHO reported no map cracking. ARAN reported no scaling.

Both the manual and the automated survey method reported low severity lane shoulder separation. The automated survey also reported one to five low severity edge punchouts. Two low severity edge punchouts were recorded by the manual survey method. In addition, the manual method indicated moderate pumping, while the automated method reported high pumping. GERPHO reported transverse cracking, spalling, and longitudinal cracking on this section. ARAN reported a few low severity potholes and the Laser RST noted that the shoulder dropped off more than an inch from the pavement.

Section R2

This CRCP section was located on the southbound lane of the Columbus bypass on State Highway 71, a heavily trafficked, four-lane divided highway. The pavement was in good condition. A replicate test (101) was done on this section.

Transverse cracking was reported by all three visual survey methods. Both mapping and the manual survey method reported over 200 cracks. Mapping showed only low severity cracks while the manual and data logger methods reported low, medium, and high levels of cracking. Both the manual and data logger methods showed high repeatability in the survey of blind replicate section 101. There was no variation between the initial and replicate surveys of section R2. GERPHO reported over 100 transverse cracks. ARAN reported a crack spacing of 0 to 20 feet (0 to 6.1 m) (greater than 50 cracks for this 1000-foot (305 m) section) on the initial test but greater than 250 feet (76.2 m) (less than 4 cracks) on the replicate run. PASCO reported a crack ratio of about 32 percent for both initial and replicate tests. The RST did not detect any transverse crack on the CRCP sections. However, after some adjustment in software, the RST reported transverse cracks in some CRCP sections which were rerun.

The data logger was the only method which observed map cracking. However, in the blind replicate data logger survey of Section R2 (Section 101), map cracking was not reported.

Three low severity depressions were recorded by manual survey method on Section R2. Manual recording showed two low severity edge punchouts while automated recording gave a range of 3 to 5 low severity edge punchouts. Moderate and high pumping was observed by the manual and automated survey methods, respectively. Both methods reported low severity lane/shoulder separation. One corner break and 66 linear feet (20 m) of low severity longitudinal cracking was reported by the manual survey method. One to five low severity patches and one to two areas of patch adjacent slab deterioration were shown by the automated method. The manual method recorded 180 square feet (16.7 square meters) of area in a moderate PCC patch. Within this patch, 12 linear feet (3.7 m) of spalling was recorded by the manual method. GERPHO and ARAN also reported spalling. ARAN reported a few low severity potholes on the initial test and no potholes on the replicate test. The Laser RST reported a shoulder dropoff of greater than one inch.

<u>Section R3</u>

Section R3 was located on the westbound side of Interstate Highway 10, a four-lane, divided, heavily trafficked highway. It was considered to be a section in good condition.

Transverse cracking was reported by all visual survey methods. Mapping and the manual survey method observed approximately the same number of cracks (over 300) at low and moderate severity levels. Both the manual and data logger methods also showed high severity level cracking. GERPHO reported almost 300 cracks. PASCO reported a crack ratio of about 92 percent. ARAN reported a crack spacing of 0 to 20 feet (0 to 6.1 m) (over 50 cracks). The Laser RST reported over 100 transverse cracks in the rerun.

Mapping reported low severity map cracking while the other two visual methods showed moderate levels. This resulted from the different methods used to rate severity levels by each visual survey. Mapping distinguished between severity levels of map cracking simply by the presence and severity of scaling in the section while the manual and data logger survey methods distinguished between severity levels by the extent or percent of slab (or section) scaled. GERPHO reported low severity map cracking. ARAN reported no scaling. One low severity depression was recorded by the manual survey method.

Pumping was rated high and low severity by the manual and automated systems, respectively. GERPHO also noted low severity pumping. The manual system reported low severity longitudinal joint spalling. The manual system also reported a quantity of twelve low severity edge punchouts, while the automated system reported a range of 11 to 15 and mapping estimated ten low severity punchouts. A range of 6 to 30 feet (1.8 to 9.1 m) of low severity longitudinal cracking was observed by the automated system and the manual system reported 18 feet (5.5 m) of low severity longitudinal cracking. Mapping estimated 56 feet (17 m) of longitudinal cracking. GERPHO reported 34 linear feet (10 m) of longitudinal cracking. Mapping also noted popouts and the manual and automated visual surveys both reported low level lane/shoulder separation.

<u>Section R4</u>

Section R4 was a JRCP type and was considered to be in moderate condition. It was located on the northbound side of the five-lane State Highway 60, a heavily trafficked highway.

No transverse cracks were observed by any of the methods or devices. However, PASCO reported a crack ratio of 0.3 percent.

Low severity map cracking was reported by mapping and the data logger. The manual survey method showed no map cracking. ARAN reported no scaling.

Mapping noted popouts and low severity spalling of joints and cracks. The manual method recorded corner breaks, lane/shoulder dropoff, and spalling. All of these distresses were low severity. The automated data logger showed a range of one to five low severity patches and a range of one to five low severity depressions. Pumping was recorded as high severity. One to two areas of durability "D" cracking was indicated for low severity and high severity levels. Lane/shoulder separation was recorded as high severity. GERPHO and ARAN reported spalling. ARAN also reported one pothole.

Section R5

Section R5 was CRCP, located on westbound Interstate Highway 10, a four-lane, divided, heavily trafficked highway. The section was considered to be in moderate condition.

Each visual survey method observed both low and moderate severity levels of transverse cracking. Mapping, the manual survey method, and GERPHO all reported over 300 transverse cracks. The Laser RST reported about 130 cracks. PASCO reported a crack ratio of 101 percent. ARAN reported a crack spacing of 0 to 20 feet (0 to 6.1 m) (over 50 cracks).

The three visual methods reported map cracking in Section R5 but mapping and the manual method indicated low severity map cracking while the automated method reported moderate levels of map cracking. GERPHO also reported low severity map cracking. ARAN reported no scaling.

The manual method rated pumping at high severity, as did the automated method. Mapping reported construction joints at low severity and the data logger reported them at moderate severity. Mapping noted several popouts. The data logger showed 31 to 40 low severity edge punchouts, and the manual method showed 39 low level punchouts. Thirty-six linear feet (11.0 m) of low level longitudinal cracking was reported by the manual method. The data logger agreed, reporting 36 to 60 linear feet (11 to 18 m) of low severity longitudinal cracking. However, the manual method also showed 46 linear feet (14 m) of moderate severity longitudinal cracking. Both the manual and automated systems reported low level lane/shoulder separation. GERPHO reported transverse and longitudinal crack spalling and two corner breaks.

Section R6

Section R6 was located on westbound Interstate Highway 10 in approximately the same location as Section R5. It was also CRCP in moderate condition.

Transverse cracking was observed by all three visual survey methods. The two detailed survey methods reported low, moderate, and high severity cracking. Mapping indicated low and moderate severity cracking. Mapping, the manual survey method, and GERPHO reported around 300 transverse cracks. The data logger reported greater than 40 cracks (the maximum range). ARAN reported a crack spacing of 0 to 20 feet (0 to 6.1 m) (over 50 cracks). The Laser RST reported 125 cracks. PASCO reported a crack ratio of 96 percent. Mapping showed low severity map cracking throughout the section, the manual survey method showed moderate map cracking, while the automated method showed high levels of this distress. This discrepancy may be due to the difference in the definition of map cracking severity levels as discussed for Section R3. GERPHO reported low severity map cracking and ARAN reported no scaling.

All visual survey methods reported patches in good condition. Mapping indicated several popouts. Manual and automated methods agreed upon the presence and severity of depressions, punchouts, longitudinal cracking, patching, and lane/shoulder separation. However, the manual method reported pumping at high severity whereas the data logger indicated low severity. The manual method also reported two linear feet (0.6 m) of longitudinal joint spalling. GERPHO reported transverse crack spalling, longitudinal cracking, and pumping. ARAN reported spalling and two potholes.

Section R7

Section R7 was JRCP and located near Section R4 on northbound State Highway 60. It was considered to be in poor condition. A repeat test was done for this section.

No transverse cracking was observed by any of the detailed visual survey methods. GERPHO and ARAN also reported no transverse cracking. PASCO reported a crack ratio of 0.6 percent on the first test and 0.7 percent on the repeat test. The Laser RST reported 46 transverse cracks.

The manual survey method did not report any map cracking. Mapping reported this distress at low and high levels of severity and the automated method reported high levels of map cracking. These discrepancies existed because of the differences in rating severity levels for this distress as discussed for Section R3. ARAN reported zero scaling on the initial and repeat test.

Mapping reported several popouts present on Section R7. Both mapping and manual survey indicated spalling of the joints. In addition, the manual method reported some moderate joint seal damage. The data logger rated pumping as moderate, and lane/shoulder separation as low severity. One to two low, three to five moderate, and one to two high areas of durability "D" cracking was also indicated by the automated data logger. GERPHO also noted spalling of the joints. ARAN noted three potholes and joint sealant loss on the initial test and the same distresses were noted on the repeat run, with coarse aggregate loss also noted.

Section R8

This section was located on the westbound side of Interstate Highway 10 in approximately the same location as Section R5. It was a CRCP considered to be in poor condition. A repeat test and a replicate test (105) was done for Section R8.

Both detailed visual survey methods reported that all levels of severity of transverse cracking were present while mapping reported low and moderate levels. Both mapping and the manual survey method reported approximately 320 transverse cracks. The manual survey method also reported 320 cracks on the repeat run. The data logger reported more than 40 cracks on both initial and replicate runs. GERPHO reported about 270 cracks. PASCO reported a crack ratio of about 84 percent for both initial and repeat runs and 101 percent for the replicate run. ARAN, for initial, repeat, and replicate runs, noted crack spacings of 0 to 20 feet (0 to 6.1 m) (over 50 cracks). The Laser RST reported approximately 100 cracks for initial and repeat tests.

Mapping and the automated method observed only low severity map cracking while the manual method observed only moderate levels in the section. This variation may be due to the different methods used to rate severity levels of map cracking as noted previously. GERPHO also noted low severity map cracking and ARAN reported no scaling.

Several popouts were reported by mapping. All visual survey methods reported patch deterioration. The data logger also reported six to ten areas of patch adjacent slab deterioration. All three visual survey methods agreed on the presence of edge punchouts and longitudinal cracking. Both the manual and automated data logger agreed that medium severity bleeding, a few low severity depressions, and low severity lane/shoulder separation were present. The manual system also reported one low severity swell. GERPHO noted transverse crack spalling along with longitudinal cracking. ARAN noted potholes, corner cracks, and longitudinal cracks on the first test; potholes, spalling, and longitudinal cracks on the repeat test; and potholes on the replicate run.

Section R9

Section R9, a CRCP section, was considered to be in poor condition. It was located near section R5 on the westbound side of Interstate Highway 10.

All three visual survey methods reported low and moderate transverse cracking. The data logger reported over 40 cracks. Mapping reported 425 cracks and the manual survey method reported 350 cracks. GERPHO reported 300 cracks, the Laser RST reported 150. ARAN noted a crack spacing of 0 to 20 feet (0 to 6.1 m) (over 50 cracks). PASCO reported a crack ratio of 94 percent.

All three visual survey methods and GERPHO reported low severity map cracking on Section R9. ARAN reported no scaling.

All visual survey methods agreed longitudinal cracking and punchouts were present on Section R9. Mapping reported several popouts too. Both manual and automated survey systems reported moderate bleeding, low lane/shoulder separation, and low severity patching. Six to ten areas of patch adjacent slab deterioration were also reported by the data logger, as well as one to two low level depressions. One corner break was also noted by the manual system. GERPHO noted transverse crack spalling and longitudinal cracking. ARAN noted spalling, potholes, and longitudinal cracking.

COMPOSITE PAVEMENT TEST SECTIONS

Table 23 presents a summary of the linear cracking (sum of all cracking given in units of length) reported on each composite pavement test section by each method or device. A section-by-section discussion and comparison of linear cracking and other distresses reported to be found on the composite test sections follows.

Section C1

Section C1, a composite pavement consisting of a flexible surface layer over CRCP, was located on the outside, westbound lane of IH 10, a four lane divided highway with heavy traffic. Section C1 was considered to be in good condition.

Table 24. Comparison of reported linear cracking for composite pavement sections.

SECTION	DISTRESS *	MAPPING (Linear Feet)	DETAILED VISUAL SURVEY Manual (Linear Feet)	DETAILED VISUAL SURVEY Automated Data Logger (Linear Feet)	GERPHO (Linear Feet)	PASCO (Crack Ratio, %) (a)	ARAN (Linear Feet)	LASER RST ** Quantity
C1	Severity	Low	Low, Moderate	Low	Low	--	0	--
	Extent	2130	38	72-120	60	0.2	0	7
C3	Severity	Low, Mod., High	Low, Mod., High	Low, Mod., High	Low, Mod.	--	Moderate	--
	Extent	3420	1245	>2612	1246	21.3	240-640	34 (a)
104 (Replicate of C3)	Severity	--	--	Low, Mod., High	--	--	Moderate	--
	Extent	--	--	>2564	--	21.4	120-320	26(a)
C8	Severity	Low	Low, Moderate	Low	Low	--	Low	--
	Extent	2180	1006	2072-2120	886	4.5	102-360	0
C5	Severity	Low, Moderate	Low, Moderate	Low, Moderate, High	Low	--	--	--
	Extent	2680	2445	>2252	1627	36.8	--	115(a)
102 (Replicate of C5)	Severity	--	--	--	--	--	Low	--
	Extent	--	--	--	--	36.9	120-320	110(a)
C7	Severity	Low, Mod., High	Low, Mod., High	Low, Moderate, High	Low	--	Low	--
	Extent	2625	2058	>4324	1185	10.6	180-480	2
C9 (Initial)	Severity	Low, Mod., High	Low, Moderate	Low, Moderate, High	Low, Mod. High	--	Moderate	--
	Extent	3450	3252	>5720	659	54.3	69-250	43(a)
C9 (Repeat)	Severity	--	--	--	--	--	Moderate	--
	Extent	--	--	--	--	54.3	400-1200	46(a)
103 (Replicate of C9)	Severity	--	--	Low, Moderate High	--	--	Low	--
	Extent	--	--	>4564	--	54.0	240-720	44(a)

* Based on the standard procedure used by each device or method.

** Includes only transverse cracks.

(a) Includes alligator cracking.

Note: 1 linear foot = 0.3048 m.

Mapping recorded longitudinal, transverse, and joint reflection cracking, and reflection cracking at the PCC pavement edge. The combination of all this linear cracking resulted in a total estimate of 2130 linear feet (649 m) of low severity cracking.

The manual detailed survey method recorded longitudinal and transverse cracking. The total of this cracking was 38 feet (11 m) of low and moderate severity linear cracking.

The automated data logger observed only transverse cracking. The total of this cracking was 72 to 120 feet (22 to 37 m) at low severity.

GERPHO rated longitudinal, transverse and reflection cracking, and potholes for Section C1. The linear cracking totalled 60 feet (18 m) of low severity.

PASCO reported a crack ratio of 0.2 percent. This ratio included all types of cracking and patching. ARAN reported alligator cracking, potholes, map cracking, and transverse cracking for this section. The Laser RST reported seven transverse cracks.

Section C3

Section C3 was a composite pavement consisting of a flexible surface layer over JRCP. This section was located on the eastbound lane of US 90, a two-lane highway. Section C3 was considered to be in good condition. A replicate test (104) was done for this section.

Mapping indicated raveling, joint reflection cracking. longitudinal cracking, and transverse cracking for this section. The addition of the linear cracking resulted in a total of 3420 linear feet (1042 m). Low, moderate, and high severity levels were noted.

Lane/shoulder dropoff, edge cracking, joint reflection cracking, longitudinal and transverse cracking, slippage cracking, and patching were observed by the manual visual survey method. Total linear cracking was found to be 1245 linear feet (380 m). All severity levels were reported.

The automated data logger rated existing patching, edge cracking, alligator cracking, block cracking, transverse cracking, longitudinal cracking, rutting, and raveling. Greater than 2612 feet (796 m) of combined linear cracking was reported at all severity levels for the initial test. The replicate test reported over 2564 feet (781 m) of linear cracking.

GERPHO reported block cracking, reflection cracking, and lane/shoulder separation. Reflection cracking totalled 1246 linear feet (380 m) of low and moderate severity.

PASCO reported a crack ratio of about 21 percent for both the initial and replicate tests. ARAN reported raveling, distortion, potholes, and alligator, longitudinal, and transverse cracking for the initial run and potholes and alligator, longitudinal, and transverse cracking on the replicate run. The Laser RST reported alligator, edge, longitudinal and random cracking, as well as lane/shoulder dropoff for both the initial and replicate tests. Approximately 30 transverse cracks were measured by the Laser RST for both tests, however, this number included alligator cracking.

Section C8

Section C8, considered to be in moderate condition, was located on the outside, westbound lane of IH 10, a four-lane divided highway with heavy traffic. This composite pavement consisted of CRCP overlaid with asphaltic concrete. Mapping recorded edge cracking, reflection cracking at the PCC pavement edge, patching, and joint reflection cracking. Total linear footage of cracking was reported to be 2180 feet (664 m) of low severity.

The manual detailed visual system of condition survey reported joint reflection cracking, longitudinal and transverse cracking, and patching.

Total linear footage of cracking was found to be 1006 feet (307 m) at both low and moderate severity levels.

Patching/potholes, alligator cracking, transverse cracking, longitudinal cracking, and rutting were found by the automated survey system. For this method, a range of 2072 to 2120 feet (631 to 646 m) of linear cracking was totalled, all low severity.

GERPHO reported longitudinal and reflection cracking as well as one pothole for Section C8. Cracking totalled 886 linear feet (270 m).

PASCO reported a crack ratio of 4.5 percent. ARAN and the Laser RST both reported longitudinal cracking for this section.

Section C5

Section C5, considered to be in poor condition was a composite pavement section consisting of a flexible layer over CRCP. It was situated in the outside, westbound lane of IH 10, a four-lane divided highway with heavy traffic. A replicate test (102) was done for this section.

Mapping indicated raveling, joint reflection cracking, reflection cracking at the PCC pavement edge, longitudinal cracking, transverse cracking, and alligator cracking. A total of 2680 feet (817 m) of linear cracking was reported for both low and moderate levels.

The manual detailed survey system rated rutting, patching, longitudinal and transverse cracking, joint reflection cracking, and alligator cracking. Total linear cracking for this method was to 2445 feet (745 m) of low and moderate levels.

Alligator cracking, transverse cracking, longitudinal cracking, raveling, and patches/potholes were rated by the automated data logger. Total linear cracking was reported greater than 2252 feet (686 m) for all severity levels.

GERPHO reported alligator, longitudinal, transverse, block, and reflection cracking, as well as raveling and potholes. Linear cracking totalled approximately 1600 feet (488 m) of low severity.

PASCO reported a crack ratio of approximately 37 percent for both initial and replicate tests. ARAN did not report results for the initial test but reported alligator, longitudinal, and transverse cracking and raveling. The Laser RST noted alligator, longitudinal, and transverse cracking as well as lane/shoulder dropoff for both initial and replicate tests.

Section C7

Located on the outside, southbound lane of IH 60, a four-lane highway was Section C7, which consisted of a flexible surface layer over JRCP. Section C7 was considered to be in poor condition.

Mapping found alligator cracking, bleeding, longitudinal cracking, patching, joint reflection cracking, and transverse cracking. The distresses measured in linear feet combined to make a total of 2625 feet (800 m) for all severity levels.

The manual survey method rated alligator cracking, bleeding, bumps and sags, joint reflection cracking, lane/shoulder dropoff, longitudinal and transverse cracking, and rutting. A total of 2058 linear feet (627 m) was calculated for all three severity levels from all linear cracking.

Patching/potholes, bleeding, alligator cracking, transverse cracking, longitudinal cracking, rutting, and raveling were reported by the automated survey system. Distresses measured in linear feet totalled to greater than 4324 feet (1318 m) for all severity levels.

GERPHO reported alligator, longitudinal, transverse, and reflection cracking, as well as bleeding and raveling for this section. Linear cracking totalled 1185 feet (361 m) of low severity.

PASCO reported a crack ratio of 10.6 percent. ARAN reported bleeding, distortion, potholes, and longitudinal and transverse cracking. The Laser RST noted lane/shoulder dropoff and two transverse cracks.

<u>Section C9</u>

Section C9 was classified as a poor condition section and consisted of a flexible layer over JRCP. It was located on the eastbound lane of US 90, a two-lane highway. A repeat test and a replicate test (103) was done for Section C9.

Block cracking, longitudinal cracking, patching, joint reflection, and transverse cracking were observed by the mapping crew. Distresses measured in linear feet totalled 3450 feet (1052 m) for all severity levels.

The manual detailed visual survey system reported bumps and sags, joint reflection cracking, lane/shoulder drop off, and longitudinal and transverse cracking. linear footage totalled 3252 feet (991 m) for low and moderate severity levels.

The automated survey system rated patching/potholes, edge cracking, alligator cracking, block cracking, transverse cracking, longitudinal cracking, and raveling. Total linear footage came to greater than 5720 feet (1743 m) for all severity levels.

GERPHO reported block cracking, reflection cracking, and lane/shoulder separation for this section. Low, moderate, and high reflection cracking, totaling 659 feet (201 m) was reported.

PASCO reported a crack ratio of about 54 percent for initial, repeat, and replicate sections. ARAN reported raveling, potholes, and longitudinal and transverse cracking for both initial and repeat tests. On the replicate run, the same distresses were reported, except raveling was omitted. The Laser RST reported alligator, edge, longitudinal, random, and transverse cracking, and lane/shoulder dropoff for initial, repeat, and replicate tests.

APPENDIX D. COST ANALYSES OF THE SELECTED DISTRESS SURVEY METHODS

Cost analyses, based on equipment, operating, and data processing costs were performed for each of the selected distress survey methods and devices. Several simplifying assumptions were used, including: 1) all equipment and data processing facilities are available in the continental United States, 2) all operators are adequately trained, and 3) the required output for each method is 3000 lane miles (4827 km) per year.

MANUAL METHODS

Table 41 presents the cost analyses for the three manual methods; mapping, detailed visual survey with manual recording, and detailed visual survey with automated data logger. The acquisition cost is approximate and includes the cost of a pickup truck, measuring tapes, and a straightedge. The cost of a portable microcomputer is included for the automated data logging. Assuming an expected equipment life of seven years and a salvage value of 10 percent, the depreciation can be calculated. Insurance, maintenance, and service costs are then calculated based on the depreciation as noted in Table 41. The total ownership cost for each unit, the sum of these items, is then presented.

During the project field tests, it was noted that the time needed to map a 100-foot (30.5 m) subsection was approximately 30 minutes. The detailed visual surveys required approximately 30 minutes for a 1000-foot (305 m) section. Using these figures, mapping can given an output of about 1 lane mile (1.6 km) per week and the detailed visual surveys, about 10 lane miles (16 km) per week. Thus, for the required 3000 lane miles (4827 km) per year survey, 60 mapping crews are needed, and 6 crews for each of the detailed visual surveys. A total equipment cost can then be calculated, as shown in Table 41.

Operating costs, based on mobilization, gas and oil, traffic control, and field data collection costs are also presented in Table 41. It is assumed that each unit will require mobilization four times per year, requiring four days each time. Transportation and testing mileage is

Table 41. Cost analysis for manual methods.

Item	GERPHO	PASCO-ROADRECON	ARAN	Laser RST
<u>Equipment Cost</u>				
(a)Acquisition cost/unit	$300,000	$500,000	$400,000	(lease only)
(b)Expected life, years	15	15	15	-
(c)Salvage value, percent	20	20	20	-
(d)Depreciation = D D = (a)[1-(c/100)]/(b)	$16,000/yr	$26,667/yr	$21,333/yr	-
(e)Investment, insurance, & storage cost = 0.5D	$8000/yr	$13,333/yr	$10,667/yr	-
(f)Maintenance & repair of equipment other than on-board computer = 0.3D	$4800/yr	$8000/yr	$6400/yr	-
(g)Maintenance & service of on-board computer = 0.1D	None	None	$2133/yr	-
(h)Total ownership cost/unit H = (d+e+f+g)	$28,800/yr	$48,000/yr	$40,533/yr	-
(i)Number of units (crews) required for 3000 lane miles/year survey	1	1	1	-
(j)<u>Total equipment cost</u> (per lane mile) = [h x i]/3000	$9.60/lane mile	$16/lane mile	$13.51/lane mile	$20/lane mile (on lease)
<u>Operating Cost</u>				
(a)Number of units (crews) required for 3000 lane miles/year survey	1	1	1	1
(b)Required number of operators/unit	2	2	3	3
(c)Mobilization/demobilization, four times per year (4 days each time) at $300/day/operator, includes subsistence	$3.20/lane mile	$3.20/lane mile	$4.80/lane mile	$4.80/lane mile

Table 41. Cost analysis for manual methods (continued).

Item	Manual Mapping	Detailed Visual Surveys: Manual Recording	Detailed Visual Surveys: Automated Data Logger
(d)Gas & oil during transportation & testing (for 2 x 3000 miles at $0.10/mile by each crew)	$12.00/lane mile	$1.2/lane mile	$1.2/lane mile
(e)Traffic control cost (6 hours per lane mile for each crew at $3 per hour for 1/10 of the 3000 lane miles per year)	$108.00/lane mile	$10.8/lane mile	$5.40/lane mile (half of the cost calculated for manual recording)
(f)On-site field data collection cost at $200/day/operator for 250 days/crew	$2000/lane mile	$200/lane mile	$100/lane mile
(g)On-board data processing cost	None	None	None
(h)<u>Total operating cost</u> = (c+d+e+f+g)	$2248/lane mile	$225/lane mile	$113/lane mile
<u>Data Processing Cost</u>			
(a)Field data processing	None	None	None
(b)Office data processing & reports at $12 per manhour	$216/lane mile (18 manhours/lane mile)	$36/lane mile (3 manhours/lane mile)	$12/lane mile (1 manhour/lane mile)
(c)<u>Total data processing cost</u> = (a + b)	$216/lane mile	$36/lane mile	$12/lane mile
Total Cost (Sum of equipment, operating, and data processing total costs)	$2533/lane mile	$268/lane mile	$132/lane mile

assumed to be a total of 6000 miles (9654 km) per year. Traffic control is assumed to be needed for 10 percent of the 3000 lane miles (4827 km) per year. The automated data logging survey can be primarily conducted from the shoulder, thus the associated traffic control cost is estimated at one-half the calculated cost for manual recording. It is also assumed that each operator will collect field data 250 days out of the year. No on-board data processing costs are required for the manual methods.

Data processing costs are estimated based on the average time taken to process data for this study. Total costs are then presented as a sum of equipment, operating, and data processing costs.

HIGH-SPEED METHODS

Table 42 presents the cost analyses for the four high-speed methods; GERPHO, PASCO, ARAN, and Laser RST. Due to proprietary data and the confidentiality of price quotes, exact information for costs could not be obtained from the participants. Thus, all costs are approximate.

Equipment costs are calculated in the same manner as the manual methods except for the Laser RST which is leased. The operating costs are also calculated in the same manner as the manual methods. No traffic control is needed for the four high-speed methods. The Laser RST is the only device that requires on-board data processing but no raw data or film processing. Office data processing and reports includes the time needed by a member of the research staff to understand the final output of the device. The total cost is presented in Table 42, as the sum of the equipment, operating, and data processing costs.

Table 42. Cost analysis for high-speed methods.

Item	Manual Mapping	Detailed Visual Surveys: Manual Recording	Detailed Visual Surveys: Automated Data Logger
<u>Equipment Cost</u>			
(a)Acquisition cost/unit	$15,000	$15,000	$15,500
(b)Expected life, years	7	7	7
(c)Salvage value, percent	10	10	10
(d)Depreciation = D D = (a)[1-(c/100)]/(b)	$1928.57/year	$1928.57/year	$1992.86/year
(e)Investment, insurance, & storage cost = 0.5D	$964.28/year	$964.28/year	$996.43/year
(f)Maintenance & repair of equipment other than on-board computer = 0.3D	$578.57/year	$578.57/year	$597.86/year
(g)Maintenance & service of on-board computer = 0.05D	None	None	$99.64/year
(h)Total ownership cost/unit (d+e+f+g)	$3471.42/year	$3471.42/year	$3686.79/year
(i)Numbers of units (crews) required for 3000 lane miles/year survey	60	6	6
(j)<u>Total equipment cost</u> (per lane mile) = [h x i]/3000	$69.43/lane mile	$6.94/lane mile	$7.37/lane mile
<u>Operating Cost</u>			
(a)Number of units (crews) required for 3000 lane miles/year survey	60	6	6
(b)Required number of operators/unit	2	2	1
(c)Mobilization/demobilization, four times per year (4 days each time) at $200/day/operator, includes subsistence	$128.00/lane mile	$12.80/lane mile	$6.40/lane mile

Table 42. Cost analysis for high-speed methods (continued).

Item	GERPHO	PASCO-ROADRECON	ARAN	Laser RST
(d)Gas & oil during transportation & testing (for 2 x 3000 miles at $0.10/mile by each crew)	$0.20/lane mile	$0.20/lane mile	$0.20/lane mile	$0.20/lane mile
(e)Traffic control cost	None	None	None	None
(f)On-site field data collection cost at $300/day/operator for 50 days/crew	$10.00/lane mile	$10.00/lane mile	$15.00/lane mile	$15.00/lane mile
(g)On-board data processing cost at $25 per manhour	None	None	None	$25.00/lane mile (one man hour per lane mile)
(h)Total operating cost = (c+d+e+f+g)	$13.40/lane mile	$13.40/lane mile	$20.00/lane mile	$45.00/lane mile
Data Processing Cost				
(a)Raw data or film processing at $12 per manhour	$18.00/lane mile (1.5 man-hour/lane mile)	$18.00/lane mile (1.5 man-hour/lane mile)	None	None
(b)Office data processing & reports at $12 per man hour	$42.00/lane mile (3.5 man hour/lane mile)	$60.00/lane mile (5 man hour/lane mile)	$66.00/lane mile (5.5 man hour/lane mile)	$24.00/lane mile (2 man hour/lane mile)
(c)Total data processing cost = (a + b)	$60/lane mile	$78/lane mile	$66/lane mile	$24/lane mile
Total Cost (Sum of equipment, operating, and data processing total costs)	$83.00/lane mile	$107/lane mile	$100/lane mile	$89/lane mile

SUMMARY

Table 43 summarizes the results of the cost analyses of the manual methods and the high-speed devices. It can be seen that the high-speed devices are very cost-effective. This cost analysis was based on a 3000 lane mile (4827 km) per year survey. Each high-speed device can easily survey 9000 or more lane miles (14,480 km) per year. Therefore, with efficient use of these devices, the cost effectiveness will increase.

Table 43. Summary of cost analyses.

Method	Equipment Cost	Operating Cost	Data Processing Cost	Total Cost
Mapping	$69.43	$2248.00	$216.00	$2533
Manual Recording	6.94	225.00	36.00	268
Automated Data Logging	7.37	113.00	12.00	132
GERPHO	9.60	13.40	60.00	83
PASCO ROADRECON	16.00	13.40	78.00	107
ARAN	13.51	20.00	66.00	100
Laser RST	20.00	45.00	24.00	89